Vol. XLI. JUNE, 1899.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

No. 848.

THE ACCURACY AND DURABILITY OF WATER METERS.

By JOHN W. HILL, M. Am. Soc. C. E.

PRESENTED FEBRUARY 1ST, 1899.

WITH DISCUSSION.

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The primary question to be discussed was the relative value of high and low-priced meters for water measurement in domestic service pipes; next, the precision of registry of the different kinds and makes of meters, with widely varying rates of delivery; and, finally, the loss of pressure by passing different quantities of water through the meters in a given length of time. The unit of time has been taken at one hour, and the delivery of the meter is stated in gallons.

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Seventeen different meters were examined, as follows:

The Worthington meter, from Henry R. Worthington, New York City.

The Union Rotary and Columbia meters, from The Union Water Meter Company, Worcester, Mass.

The Crown, Empire and Nash meters, from the National Meter Company, New York City.

The Hersey and Hersey Disc meters, from the Hersey Manufacturing Company, Boston, Mass.

The Lambert (Bee) meter, from The Thomson Meter Company, Brooklyn, N. Y.

The Trident Disc meter, of which several were purchased by the Village Water-Works, 1896.

The Niagara meter, from The Buffalo Meter Company, Buffalo, N. Y.

The Pittsburg Disc meter (two styles), from the Pittsburg Meter Company, East Pittsburg, Pa.

The Standard Disc meter, from The Standard Meter Company, New York City.

Of this list, the Worthington, Union Rotary, Crown, Empire and Hersey are so-called piston meters; the Nash, Hersey Disc, Lambert, Trident, Niagara, Pittsburg and Standard are disc meters, and the Columbia a velocity or inferential meter.

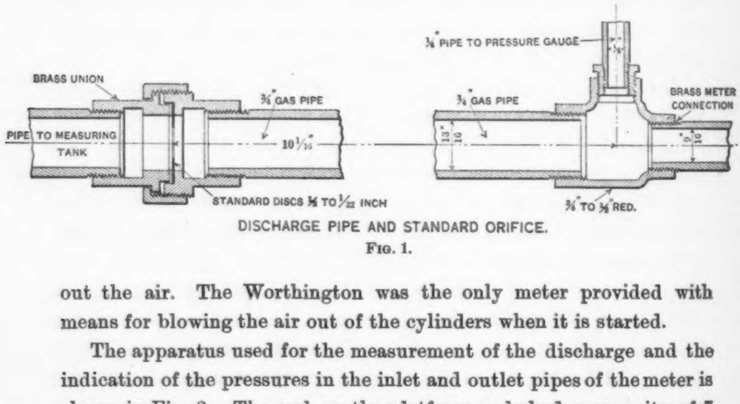
While the original object of this investigation was information for the guidance of the trustees of the village water-works in the selection of meters for local use, it has occurred to the author that the data may be of interest to others connected with the management of public water-works. Incidentally, it may be of some interest to the manufacturers of meters, and may possibly lead to the correction of defects which were manifested in some of the meters when tested on small streams.

The tests were made under the ordinary conditions of service to a residence, the ¾-in. service pipe being connected with the meters singly, and no flow through the pipe for domestic uses being permitted while a meter was under test.

The static pressure on the service pipe varied from 85 to 106 lbs., the main in the street in front of the building where the tests were conducted serving as a rising main to the reservoir during the day when the pumps were running, and as a supply main from the reservoir at night when the pumps were stopped, the pressure thus being highest during the day.

The distance from the 10-in. cast-iron main to the meter, measured along the ¾-in. iron supply pipe, was about 107 ft., and there were five ¾-in. bends. The supply was taken through an ordinary galvan-

ized iron pipe measuring $\frac{13}{16}$ in., internal diameter, with gas-pipe fittings. No effort was made to accommodate the meters in the arrangement of the pipe, the condition desired being as nearly as possible like that of a meter placed in the line of a domestic service pipe. The varying rates of discharge were obtained by placing in the short piece of $\frac{3}{4}$-in. pipe attached to the outlet connection of the meter, brass discs, 0.0265 in. thick, with central perforations ranging from $\frac{1}{2}$ in. to $\frac{1}{32}$ in. diameter. The discs were held against a thin rubber gasket in a brass union recessed as shown in Fig. 1. The flow of water to the meter was controlled by a lever stop-cock in the supply pipe below the pressure-gauge. During each test the stop-cock was set at full opening, and the flow of water through the meter controlled entirely by the standard orifice in the discharge pipe. Before any test was started, the meter was run for some time at full opening to work



DISCHARGE PIPE AND STANDARD ORIFICE.
FIG. 1.

out the air. The Worthington was the only meter provided with means for blowing the air out of the cylinders when it is started.

The apparatus used for the measurement of the discharge and the indication of the pressures in the inlet and outlet pipes of the meter is shown in Fig. 2. The cask on the platform scale had a capacity of 7 cu. ft., and the scale beam was graduated to half pounds. By hanging the sliding poise on the saw teeth of the beam, weights to quarter pounds could be noted.

The results of the tests of the meters at different rates of delivery are given in Table No. 1, first, for each of the piston meters; next, for the disc meters, and, finally, for the velocity or inferential meter. In all cases the meter was brought to the zero point of the 1-cu. ft. dial, the tare of the measuring cask taken, and from 1 to 6 cu. ft. of water drawn through the meter and caught in the cask. The net

contents of the cask were reduced to cubic feet for observed temperature of water, and the discharge, as noted by tank measurement, divided by the difference of meter reading, *i. e.*, by the discharge as indicated by the meter.

TABLE No. 1.

Piston Meters.

Résumé of Test of ⅝-In. Worthington Meter, No. 100 020. October 20th and 21st, 1898.

Order of Test, 15.

Number of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temperature of water, degrees.
3.........	½	29.66	828.27	5.000	5.0443	1.0089	56
3.........	¼	65.00	531.30	5.000	5.0443	1.0089	56
4.........	⅛	92.47	172.25	3.000	2.9655	0.9885	57
6.........	1/16	98.36	45.34	2.016	2.0020	0.9933	58
2.........	1/32	87.77	10.82	1.000	0.9064	0.9064	58

Résumé of Test of ⅝-In. Crown Meter, No. 187 595. October 7th and 10th, 1898.

Order of Test, 9.

4.........	½	32.75	872.85	5.000	5.2829	1.0566	56
3.........	¼	69.66	546.31	4.333	4.5025	1.0392	58
2.........	⅛	92.95	172.68	3.000	3.1807	1.0602	60
3.........	1/16	99.76	45.66	3.000	3.2302	1.0767	60
3.........	1/32	93.62	11.18	1.000	1.1044	1.1044	61

Résumé of Test of ¾-In. Hersey Meter, No. 57 617. October 10th, 1898.

Order of Test, 10.

3.........	½	21.33	913.52	5.000	5.1889	1.0378	56
3.........	¼	68.66	559.95	5.000	5.1701	1.0340	56
4.........	⅛	92.81	172.58	3.000	2.9841	0.9947	60
....	1/16	Meter refused to work with this orifice.					

Résumé of Test of ⅝-In. Empire Meter, No. 191 159. October 1st and 3d, 1898.

Order of Test, 1.

6.........	½	23.33	746.60	6.017	6.0523	1.0058	64
4.........	¼	58.50	503.90	5.750	5.7665	1.0028	65
5.........	⅛	87.28	167.44	4.800	4.7902	0.9977	64
5.........	1/16	88.95	43.07	2.800	2.7845	0.9943	69
3.........	1/32	83.90	10.59	1.333	1.3460	1.0087	68

Résumé of Test of ⅝-In. Union Rotary Meter, No. 67 225. October 18th, 1898.

Order of Test, 13.

3.........	½	20.00	940.94	5.000	4.9836	0.9967	58
3.........	¼	71.00	581.90	5.000	4.9703	0.9942	58
3.........	⅛	98.70	178.06	3.000	2.9355	0.9786	59
3.........	1/16	102.29	46.23	2.000	1.9679	0.9840	59
4.........	1/32	88.72	10.88	1.000	1.1953	1.1953	61

TABLE No. 1—(*Continued*).

Disc Meters.

Résumé of Test of $\frac{5}{8}$-In. Nash Meter, No. 191 160. October 3d, 1898.

Order of Test, 2.

No. of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temperature of water, degrees.
3.........	$\frac{1}{2}$	22.83	933.14	5.333	5.3603	1.0050	57
3.........	$\frac{1}{4}$	70.00	573.79	5.000	5.0000	1.0000	58
3.........	$\frac{1}{8}$	92.78	172.70	4.000	4.0300	1.0076	60
3.........	$\frac{1}{16}$	95.92	44.77	3.000	3.0191	1.0063	61
3.........	$\frac{1}{32}$	94.80	11.24	1.667	1.6690	1.0004	64

Résumé of Test of $\frac{5}{8}$-In. Hersey Meter, No. 68 629. October 4th and 5th, 1898.

Order of Test, 4.

3.........	$\frac{1}{2}$	33.33	868.87	5.000	5.0472	1.0094	57
2.........	$\frac{1}{4}$	74.00	556.68	5.000	5.0126	1.0025	57
5.........	$\frac{1}{8}$	92.43	172.11	3.000	2.9614	0.9871	59
3.........	$\frac{1}{16}$	94.71	44.50	3.000	2.9800	0.9933	65
2.........	$\frac{1}{32}$	90.22	10.98	2.000	1.9943	0.9972	65

Résumé of Test of $\frac{5}{8}$-In. Trident Meter, No. 23 178. October 6th, 1898.

Order of Test, 5.

3.........	$\frac{1}{2}$	25.00	926.78	5.000	5.0019	1.0004	57
3.........	$\frac{1}{4}$	66.67	556.23	5.000	4.9857	0.9971	57
3.........	$\frac{1}{8}$	93.76	173.52	3.000	2.9813	0.9938	59
3.........	$\frac{1}{16}$	95.09	44.57	2.000	2.0055	1.0027	60
3.........	$\frac{1}{32}$	87.52	10.80	1.333	1.3910	1.0446	64

Résumé of Test of $\frac{5}{8}$-In. Trident Meter, No. 23 179. October 6th, 1898.

Order of Test, 6.

2.........	$\frac{1}{2}$	23.00	900.72	5.000	5.0006	1.0001	57
2.........	$\frac{1}{8}$	89.10	169.19	3.000	3.0000	1.0000	59
2.........	$\frac{1}{32}$	90.55	10.99	1.000	1.2600	1.2600	65

Résumé of Test of $\frac{5}{8}$-In. Trident Meter, No. 23 180. October 6th and 7th, 1898.

Order of Test, 7.

2.........	$\frac{1}{2}$	24.00	873.18	5.000	5.0893	1.0178	58
2.........	$\frac{1}{8}$	87.87	167.95	3.000	3.0403	1.0134	60
2.........	$\frac{1}{32}$	89.77	10.95	1.000	1.1633	1.1633	60

Résumé of Test of $\frac{5}{8}$-In. Trident Meter, No. 23 176. October 7th, 1898.

Order of Test, 8.

3.........	$\frac{1}{2}$	24.67	915.81	5.000	5.0447	1.0089	57
2.........	$\frac{1}{8}$	94.85	174.50	3.000	3.0199	1.0066	59
3.........	$\frac{1}{32}$	90.41	10.99	0.833	1.8749	2.2921	62

TABLE No. 1—(*Concluded*).

RÉSUMÉ OF TEST OF $\frac{5}{8}$-IN. PITTSBURG METER, No. 8 011. OCTOBER 3D AND 4TH, 1898.

Order of Test, 3.

Number of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temp. of water, degrees.
2.........	$\frac{1}{2}$	23.00	896.92	5.000	5.0293	1.0060	59
2.........	$\frac{1}{4}$	65.75	548.74	5.000	5.0333	1.0067	59
2.........	$\frac{1}{8}$	96.04	175.71	3.000	3.0244	1.0081	60
2.........	$\frac{1}{16}$	95.40	44.65	3.000	3.0768	1.0255	62
3.........	$\frac{1}{32}$	93.09	11.15	1.667	1.8779	1.1200	64

RÉSUMÉ OF TEST OF $\frac{5}{8}$-IN. PITTSBURG METER, No. 10 798. OCTOBER 10TH AND 11TH, 1898.

Order of Test, 11.

Number of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temp. of water, degrees.
3.........	$\frac{1}{2}$	20.00	907.36	5.000	4.9863	0.9973	58
2.........	$\frac{1}{4}$	65.00	557.06	5.000	4.9649	0.9930	58
3.........	$\frac{1}{8}$	90.63	170.71	3.000	2.9520	0.9842	59
3.........	$\frac{1}{16}$	102.66	46.31	2.000	2.0351	1.0176	61
2.........	$\frac{1}{32}$	94.32	11.22	1.000	1.3278	1.3278	60

RÉSUMÉ OF TEST OF $\frac{5}{8}$-IN. NIAGARA METER, No. 18 901. OCTOBER 17TH, 1898.

Order of Test, 12.

Number of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temp. of water, degrees.
3.........	$\frac{1}{2}$	19.66	894.93	5.000	4.9843	0.9968	60
3.........	$\frac{1}{4}$	64.00	548.71	5.000	4.9313	0.9863	61
3.........	$\frac{1}{8}$	88.63	168.95	3.000	2.9258	0.9753	62
3.........	$\frac{1}{16}$	90.34	43.44	2.000	1.9792	0.9896	62
3.........	$\frac{1}{32}$	101.23	11.62	1.333	1.6048	1.2062	63

RÉSUMÉ OF TEST OF $\frac{5}{8}$-IN. STANDARD METER, No........ OCTOBER 2D, 1898.

Order of Test, 16.

Number of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temp. of water, degrees.
4.........	$\frac{1}{2}$	20.00	938.18	5.000	4.9120	0.9824	56
3.........	$\frac{1}{4}$	69.66	571.70	5.000	4.8973	0.9795	56
3.........	$\frac{1}{8}$	95.76	175.23	3.000	2.9459	0.9820	56
4.........	$\frac{1}{16}$	99.70	45.65	2.000	2.1535	1.0768	58
	$\frac{1}{32}$	Meter refused to work with this orifice.					

RÉSUMÉ OF TEST OF $\frac{5}{8}$-IN. LAMBERT METER, No. 121 795. OCTOBER 24TH, 1898.

Order of Test, 17.

Number of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temp. of water, degrees.
4.........	$\frac{1}{2}$	24.50	911.27	5.000	5.0423	1.0085	56
3.........	$\frac{1}{4}$	68.92	560.57	5.000	5.0443	1.0089	56
3.........	$\frac{1}{8}$	93.15	173.03	3.000	3.0394	1.0131	56
1.........	$\frac{1}{16}$	97.68	45.17	1.000	1.2110	1.2110	56

Upon next test with $\frac{1}{16}$-in. orifice the meter stuck. The gear-train probably binds at top of case.

INFERENTIAL METER.

RÉSUMÉ OF TEST OF $\frac{5}{8}$-IN. COLUMBIA METER, No. 67 139. OCTOBER 18TH AND 19TH, 1898.

Order of Test, 14.

Number of tests.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Discharge, in gallons per hour.	Cubic feet, by meter.	Cubic feet, by tank.	Ratio of tank to meter.	Temp. of water, degrees.
3.........	$\frac{1}{2}$	40.00	762.43	5.000	5.0397	1.0079	58
3.........	$\frac{1}{4}$	67.00	511.99	5.000	5.0638	1.0127	58
3.........	$\frac{1}{8}$	95.10	172.93	3.000	3.0720	1.0240	58
6.........	$\frac{1}{16}$	98.76	45.43	2.333	2.2165	0.9508	58
4.........	$\frac{1}{32}$	92.77	11.13	2.675	0.7947	0.2968	58

Considering the accuracy of small water meters, the author was surprised at the trifling variation in errors of registry for rates of discharge, varying in some examples as 90 to 1. Thus, the Empire meter, during 23 tests, with a range of delivery from 75 to 1, varied from a minus error of 0.87% to a plus error of 0.23%, with an average error of — 0.18 per cent. The Nash meter, with a discharge varying from 83 to 1, exhibited during the 15 tests a maximum error of — 0.75%, and a minimum error of — 0.04%, with an average error of registry of 0.38 per cent. These were new meters. The Crown meter had passed 3 500 cu. ft. of water prior to the test, but, under the usual conditions of meter service, this should have had no apparent effect on its accuracy. This meter showed a maximum error of — 9.45%, and a least error of — 3.77%, with an average error for 15 tests of — 6.28 per cent. The Hersey disc meter, for 15 tests, with a range of delivery from 80 to 1, showed an average of + 0.22%, a maximum error of + 1.31%, and a minimum error of — 0.25 per cent. The Trident meter, No. 23 178, for 15 tests, gave a maximum error of — 4.27%, a minimum error of — 0.04%, and an average error of — 0.73 per cent. Table No. 2 shows the errors of all the meters tested.

TABLE No. 2.—Comparison of Errors of Registry.

Order of test.	Meter.	Number of tests.	Error.		
			Maximum.	Minimum.	Average.
		Piston Meters.			
15	Worthington	18	+10.32	+0.67	+ 2.08
9	Crown	15	— 9.45	—3.77	— 6.28
10	Hersey	10	— 3.64	+0.53	— 2.13
1	Empire	23	— 0.86	+0.23	— 0.18
13	Union Rotary	16	—16.34	+0.33	— 2.32
		Disc Meters.			
2	Nash	15	— 0.75	—0.04	— 0.38
4	Hersey	15	+ 1.31	—0.25	+ 0.22
5	Trident, No. 23 178	15	— 4.27	—0.04	— 0.73
6	Trident, No. 23 179	6	—20.63	—0.01	— 6.88
7	Trident, No. 23 180	6	—14.03	—1.32	— 5.70
8	Trident, No. 23 176	8	—56.37	—0.66	—19.30
3	Pittsburg, No. 8 011	11	—10.71	—0.60	— 3.05
11	Pittsburg, No. 10 798	13	—24.68	+0.27	— 4.77
12	Niagara	15	—17.10	+0.32	— 2.36
16	Standard	14	— 7.13	+1.79	— 0.35
17	Lambert	11	—17.42	—0.84	— 5.11
		Inferential Meter.			
14	Columbia	19	+66.31	—0.78	+13.42

An error is stated as plus when the registry of the meter was greater than the actual quantity of water delivered, and as minus when the quantity of water delivered exceeded the registry of the meter.

Certain meters, while quite accurate with ordinary rates of draught, were incapable of measuring the smaller discharges, and these smaller discharges more nearly resemble the leakage in domestic plumbing, which, with the meter system of water measurement, the average householder will be prompt to correct, in the interest of domestic economy.

This inquiry was undertaken altogether from a practical point of view, and the author has no doubt that certain meters which did not show quite as good results as other meters may be just as reliable instruments for the ordinary measurement of water supplied through service pipes.

Apart from any refinements of water measurement which may be shown by these and former tests of meters, one cannot neglect the important fact that, however precise the instrument may be under test, it must be constructed on such principles and in such a manner as will guarantee its durability and continued proper working through years of time; and it should be very gratifying to all interested in the use of meters that those meters, which in these tests have shown the greatest precision of measurement, also have demonstrated their capacity to operate for a generation or longer in daily service, and still be in a condition to satisfactorily approximate the quantity of water which is passed through them.

As a general proposition, only two or three of the meters fell so low in the author's esteem as to make them doubtful devices for the measurement of water; but any meter represented in these tests (if not damaged by use) is superior to the prevailing mode of charging for water by a survey of the premises. So long as many consumers of water from the public mains are wasting as much as they use, while others are using less than half of what they pay for, any water meter that will work with all streams, and indicate the actual quantity of water passed within 4 or 5%, will meet all present requirements. When water meters, as they should be, are used to measure every gallon of water taken for consumption from the public mains, then the refinements of meter measurement can be safely discussed.

TABLE No. 3.—Comparison of Wyoming and Boston Meter Tests.

Wyoming Tests, 1898.				Boston Tests, 1887-88.			
Diameter of orifice.	Pressure, in pounds.	Ratio of tank to meter.	Discharge, gallons per hour.	Diameter of orifice.	Pressure, in pounds.	Ratio of tank to meter.	Discharge, gallons per hour.
5/8-in. Crown, No. 187 595.				3/4-in. Crown, No. 45 073.			
1/2-in.	32.75	1.0566	872.85	1/2-in.	21	0.9902	1 082.24
1/4-in.	69.66	1.0392	546.31	1/4-in.	41	0.9902	448.80
1/8-in.	92.95	1.0602	172.68	0.15-in.	45.5	1.0021	184.01
1/16-in.	99.76	1.0767	45.66	0.05-in.	46	1.0366	23.34
1/32-in.	93.62	1.1044	11.18	0.03-in.	46	1.0552	8.53
5/8-in. Empire, No. 191 159.				3/4-in. Empire, No. 45 075.			
1/2-in.	23.33	1.0058	746.60	1/2-in.	18.5	1.0112	1 081.61
1/4-in.	58.50	1.0028	503.90	1/4-in.	41	0.9971	439.82
1/8-in.	87.28	0.9977	167.44	0.15-in.	45	0.9873	184.01
1/16-in.	88.95	0.9943	43.07	0.05-in.	46	1.0941	21.09
1/32-in.	83.90	1.0087	10.59	0.03-in.	46	1.4791	8.53
3/4-in. Hersey Rotary, No. 57 617.				3/4-in. Hersey Rotary, No. 448.			
1/2-in.	21.33	1.0378	913.52	1/2-in.	23	0.9873	973.90
1/4-in.	68.66	1.0340	559.95	1/4-in.	40	0.9872	453.29
1/8-in.	92.81	0.9947	172.58	0.15-in.	45	0.9707	188.49
5/8-in. Union, No. 67 225.				3/4-in. Union, No. 23 816.			
1/2-in.	20.00	0.9967	940.94	1/2-in.	17	1.0190	1 095.07
1/4-in.	71.00	0.9942	581.90	1/4-in.	40	1.0051	435.34
1/8-in.	98.70	0.9786	178.06	0.15-in.	44	1.0149	175.03
1/16-in.	102.29	0.9840	46.23	0.05-in.	46	8.8471	22.89
1/32-in.	88.72	1.1953	10.88	0.03-in.	46.5	91.9166	8.53
5/8-in. Worthington, No. 100 020.				3/4-in. Worthington, No. 5 990.			
1/2-in.	29.66	1.0089	828.27	1/2-in.	21	0.9974	1 050.19
1/4-in.	65.00	1.0089	531.30	1/4-in.	42	0.9810	444.31
1/8-in.	92.47	0.9885	172.25	0.15-in.	47	0.9847	192.98
1/16-in.	98.36	0.9933	45.34	0.05-in.	46	0.8848	22.89
1/32-in.	87.77	0.9064	10.82	0.03-in.	47	0.9466	8.98

The perfect meter is in the future, and doubtless will contain the principle laid down by John Thomson, M. Am. Soc. C. E.; * but, meanwhile, no one is justified in rejecting the modern displacement meter, as a device for the measurement of water, upon the theory that it is not sufficiently accurate for all practical purposes.

Water meters are not made, and should not be rated, like "Jurgensen" watches, and errors much in excess of those mentioned are admissible in practice without indicating that the water meter is a faulty machine for its purpose. In his excellent paper on water meters, Mr. Thomson states that errors of 5 to 7% should not condemn a water meter, and the author can accept this approach to accuracy of measurement provided he is quite sure that the variations of the meter from the true discharge do not exceed the limits laid down. In these and other tests of water meters which the author

* "A Memoir on Water Meters," *Transactions*, Am. Soc. C. E., Vol. xxv, p. 65.

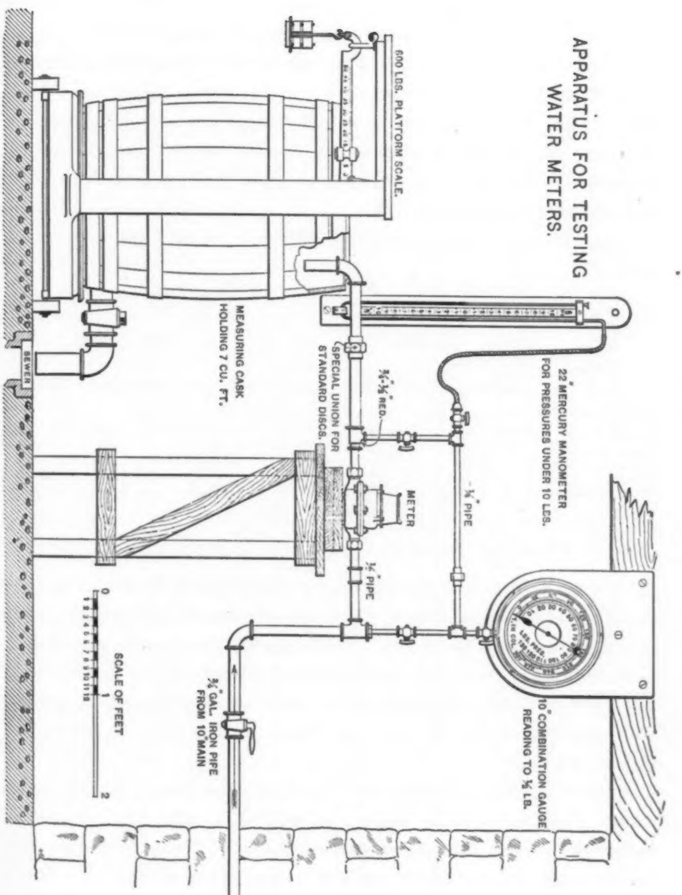

APPARATUS FOR TESTING
WATER METERS.
600 LBS. PLATFORM SCALE.
22" MERCURY MANOMETER
FOR PRESSURES UNDER 10 LBS.
MEASURING CASK
HOLDING 7 CU. FT.
SEWER
¾"-⅝" RED.
SPECIAL UNION FOR
STANDARD DISCS.
METER
¼" PIPE
⅝" PIPE
10" COMBINATION GAUGE
READING TO ¼ LB.
¾" GAL. IRON PIPE
FROM 10" MAIN
SCALE OF FEET

Fig. 2.

has made, the errors sometimes go considerably beyond 5 or 7%, and thus raise a doubt as to the general accuracy of these devices for the measurement of the widely varying streams which flow through domestic service pipes.

Perhaps the most elaborate tests of water meters ever made were conducted under the auspices of the Boston Water Board, during 1887-88, and, curiously enough, of the 26 meters tested there, only five or six, within the author's knowledge, are now offered in the market. As a matter of interest, the five meters tested, both at Boston and Wyoming, are brought together for the nearest concordant discharges in Table No. 3.

The errors of registry for these meters by these tests were as follows:

TABLE No. 4—Errors of Registry.

Meter.	Wyoming Test.			Boston Test.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Crown	− 9.45	− 3.77	− 6.28	− 5.23	+ 0.99	− 1.40
Empire	− 0.86	+ 0.23	− 0.18	+ 32.39	+ 1.29	− 8.10
Hersey	− 3.64	+ 0.53	− 2.13	+ 3.02	+ 1.29	+ 1.87
Union	− 16.34	+ 0.33	− 2.33	+ 98.91	− 0.51	− 38.31
Worthington	+ 10.32	+ 0.67	+ 2.08	+ 13.02	− 0.26	+ 4.48

Loss of Head and Reduced Capacity of Service Pipes by Meters.

During the time the meters were being tested by the author for accuracy at different rates of discharge, the pressures were taken only on the inlet side of the meter. Subsequently the pipes were arranged, as shown in Fig. 2, to take pressures on both sides of the meter. During these tests, the standard orifices were used in the discharge pipe, and pressures under 10 lbs. were taken on the mercury piezometer shown in Fig. 2.

A careful review of Table No. 5, and of Table No. 7, giving the reduced discharges with meters connected in the test apparatus, indicates that the disc meters consumed less of the static head on the service pipe, and therefore realized a larger percentage of reduced capacity than the piston or inferential meters. If the disc meter can be shown to be as durable in service, and in other respects equal to the piston and inferential meters, it is entitled to first place in the types of water meters. The author's tests were not made to show the

durability of water meters, but, from authentic data placed in his hands for professional purposes by a city water department, he is led to the conclusion that the present disc meter (if not so in all examples at present), can be made as durable as the other types of meters; and if this opinion is well founded, it must become the standard of water meters for domestic uses.

TABLE No. 5—Loss of Head by Meter.

Meter.	Diameter of orifice, in inches.	Pressure, pounds, inlet.	Pressure, pounds, outlet.	Difference, loss of head.	Percentage, loss of head.
Piston Meters.					
5/8-in. Worthington, No. 100 020...	1/2	29.00	4.69	24.30	83.81
	1/4	60.50	50.50	10.00	16.53
	1/8	85.00	84.00	1.00	1.18
5/8-in. Crown, No. 187 595..........	1/2	29.75	4.79	24.96	83.90
	1/4	68.50	57.00	11.50	16.79
	1/8	91.00	90.00	1.00	1.10
3/4-in. Hersey, No. 57 617...........	1/2	23.00	5.89	17.11	74.38
	1/4	67.50	59.50	8.00	11.85
	1/8	91.00	90.00	1.00	1.10
5/8 in. Empire, No. 191 159.........	1/2	27.50	4.17	23.33	84.84
	1/4	68.25	58.25	10.00	14.65
	1/8	91.00	90.25	0.75	0.82
5/8-in. Union Rotary, No. 67 225...	1/2	17.50	4.88	12.62	72.11
	1/4	61.00	56.00	5.00	8.20
	1/8	85.00	84.25	0.75	0.88
Disc Meters.					
5/8-in. Nash, No. 191 160............	1/2	21.00	5.40	15.60	74.29
	1/4	66.00	59.50	6.50	9.85
	1/8	90.75	90.00	0.75	0.83
5/8-in. Hersey, No. 68 629...........	1/2	31.50	4.82	26.68	84.70
	1/4	69.00	57.50	11.50	16.66
	1/8	91.50	90.50	1.00	1.09
5/8-in. Trident, No. 23 176..........	1/2	22.50	4.98	17.52	77.87
	1/4	67.00	59.00	8.00	11.94
	1/8	91.00	90.25	0.75	0.82
5/8-in. Pittsburg, No. 8 011.........	1/2	21.00	4.66	16.33	77.76
	1/4	67.00	60.00	7.00	10.45
	1/8	91.50	90.75	0.75	0.82
5/8-in. Pittsburg, No. 10 798........	1/2	20.00	5.28	14.72	73.60
	1/4	67.00	60.50	6.50	9.70
	1/8	92.75	92.00	0.75	0.81
5/8-in. Niagara, No. 18 901..........	1/2	20.50	5.57	14.92	72.80
	1/4	67.25	60.75	6.50	9.67
	1/8	91.75	91.25	0.50	0.54
5/8-in. Standard, No.	1/2	18.50	5.03	13.47	72.81
	1/4	67.50	62.00	5.50	8.15
	1/8	91 75	90.75	1.00	1.09
5/8-in. Lambert, No. 121 795........	1/2	21.50	5.03	16.47	76.59
	1/4	61.50	54.00	7.50	12.19
	1/8	85.50	84.50	1.00	1.17
Inferential Meter.					
5/8-in. Columbia, No. 67 139........	1/2	37.50	3.44	34.06	90.83
	1/4	64.50	48.50	16.00	24.81
	1/8	85.50	83.00	2.50	2.92

Losses of head with $\frac{1}{16}$ and $\frac{1}{32}$-in. orifices not measurable by the gauges used.

It is not apparent to the author why a disc meter should be subject to more rapid wear than a piston meter, nor why it should be less

convenient or more expensive to repair. It may be true that the rotary piston meters, when leakage becomes so great as to demand repair, can be taken apart and the piston box ground down or reduced in depth until the vertical play of the piston is no greater than in a new meter; but the cost of doing this—at least with small meters—will be as much or more than the cost of replacing a worn-out disc. If the pistons of the piston meters wear sufficiently at the displacement surfaces to render the registry unreliable, then new pistons become necessary, the cost of which will be much greater than new discs for the disc meters.

The loss of head and reduced discharge of house taps by the introduction of water meters may in some instances be a serious drawback, especially when the consumption should at times quite equal the capacity of the service pipe. Upon the other hand, it may be urged that the small difference of time required to fill a water-closet tank, bath tub or other domestic convenience, can constitute no serious objection to the slower meters; but in the event of water being taken through meters for domestic fire protection, then the loss of pressure and capacity becomes a very serious objection. Such a condition in connection with meters fortunately does not often arise, but it is entitled to some consideration, and manufacturers should strive to construct their machines so as to consume as little as possible of the pressure in the service pipe, while the water is passing through the meter and moving the working parts.

After the tests for accuracy of registry with the different rates of discharge, the apparatus shown in Fig. 2 was connected up with a piece of ⅝-in. galvanized iron pipe, with the burrs at the ends filed out and all visible obstructions removed, with the results noted in Table No. 6:

TABLE No. 6.—TEST FOR REDUCED DISCHARGE OF APPARATUS WITH METER REMOVED.

No. of test.	Diameter of orifice, in inches.	Time, in minutes.	Pressure in supply pipe, in pounds.	Cubic feet.	Temperature of water, degrees.	Discharge, in gallons per hour.
1.........	½	2	15.5	4.2745	56	959.198
2.........	½	2	15.3	4.2664	56	957.380
3.........	½	2	15.5	4.2344	56	950.199
17.........	½	2.5	16.0	5.4052	56	970.341
18.........	½	2.5	16.0	5.4052	56	970.341
4.........	¼	4	68.7	5.1406	56	576.775
5.........	¼	4	68.8	5.1486	56	577.673
6.........	¼	4	68.8	5.1486	56	577.673
7.........	⅛	8	94.7	3.1038	57	174.123
8.........	⅛	8	94.4	3.1038	57	174.123
9.........	⅛	8	95.0	3.1198	57	175.004

TABLE No. 7.—Reduced Discharge of Test Apparatus.

Meter.	Diameter of orifice, in inches.	Pressure on supply pipe, in pounds.	Gallons per hour, by meter.	Gallons per hour, by curve.	Percentage of reduced capacity.
		Piston Meters.			
Worthington	½	29.66	828.27	1322.0	62.65
Crown	½	32.75	872.85	1392.0	62.70
Hersey	½	21.33	913.52	1120.0	81.56
Empire	½	23.33	746.60	1170.0	63.81
Union	½	20.00	940.94	1086.0	86.64
Worthington	¼	65.00	531.30	561.3	94.66
Crown	¼	69.66	546.31	581.0	94.03
Hersey	¼	68.66	559.95	576.8	97.08
Empire	¼	58.50	503.90	532.5	94.63
Union	¼	71.00	581.90	586.8	99.16
Worthington	⅛	92.47	172.25	172.6	99.77
Crown	⅛	92.95	172.68	173.1	99.74
Hersey	⅛	92.81	172.58	173.0	99.76
Empire	⅛	87.28	167.44	167.7	99.82
Union	⅛	98.70	178.06	178.3	99.84
		Disc Meters.			
Nash	½	22.83	933.14	1158.0	80.58
Hersey	½	33.33	868.87	1403.0	61.93
Trident, No. 23 178	½	25.00	926.78	1215.0	76.28
Trident, No. 23 179	½	23.00	900.72	1163.0	77.45
Trident, No. 23 180	½	24.00	873.18	1188.0	73.50
Trident, No. 23 176	½	24.67	915.81	1205.0	76.00
Pittsburg, No. 8 011	½	23.00	896.92	1163.0	77.13
Pittsburg. No. 10 798	½	20.00	907.36	1086.0	83.55
Niagara	½	19.66	894.93	1076.0	83.17
Standard	½	20.00	938.18	1086.0	86.39
Lambert	½	24.50	911.27	1202.0	75.81
Nash	¼	70.00	573.79	582.5	98.50
Hersey	¼	74.00	556.68	599.0	92.93
Trident, No. 23 178	¼	66.67	556.23	568.2	97.89
Pittsburg, No. 8 011	¼	65.75	548.74	564.5	97.21
Pittsburg, No. 10 798	¼	65.00	557.06	561.3	99.24
Niagara	¼	64.00	548.71	556.9	98.53
Standard	¼	69.66	571.70	581.0	98.40
Lambert	¼	68.92	560.57	578.0	96.98
Nash	⅛	92.78	172.70	172.9	99.88
Hersey	⅛	92.43	172.11	172.6	99.72
Trident, No. 23 178	⅛	93.76	173.52	173.8	99.81
Trident, No. 23 179	⅛	89.10	169.19	169.5	99.82
Trident, No. 23 180	⅛	87.87	167.95	168.3	99.76
Trident, No. 23 176	⅛	94.85	174.50	174.8	99.80
Pittsburg, No. 8 011	⅛	96.04	175.71	176.0	99.84
Pittsburg, No. 10 798	⅛	90.63	170.71	170.9	99.86
Niagara	⅛	88.63	168.95	169.1	99.91
Standard	⅛	95.76	175.23	175.7	99.73
Lambert	⅛	93.15	173.03	173.3	99.84
		Inferential Meter.			
Columbia	½	40.00	762.43	1536.6	49.62
Columbia	¼	67.00	511.99	569.8	89.85
Columbia	⅛	95.10	172.93	175.1	98.73

In these tests a piece of pipe of the same length as the average measurement from out to out of meter spuds was substituted for the meters for comparison of the discharge of the simple pipe arrangement with the discharge of the several meters. From the data thus

TABLE No. 8.—COMPARISON OF WYOMING AND HAMBURG METER TESTS.

No. of test.	Diameter of orifice, in inches.	Pressure, in pounds.	Loss of head, in pounds.	Ratio of tank to meter.	Discharge, gallons per hour.
$\frac{5}{8}$-in. Lambert, No. 121 795 (Wyoming).					
223-226.......	$\frac{1}{2}$	24.50	18.75	1.0085	911.27
227-229.......	$\frac{1}{4}$	68.92	8.40	1.0089	560.57
230-232.......	$\frac{1}{8}$	93.15	1.09	1.0131	173.03
233-234.......	$\frac{1}{16}$	97.68	Not measurable.	1.2110	45.17
....	$\frac{1}{32}$	.....	" "	......	......
$\frac{3}{4}$-in. Lambert, No. 55 036 (Hamburg).					
15...........	....	44.1	7.676	1.000	834.34
14...........	....	44.1	2.843	1.000	511.23
12...........	....	44.1	0.426	1.000	194.18
8...........	....	44.1	Not measurable.	1.017	37.52
4...........	....	44.1	" "	1.053	7.66
$\frac{5}{8}$-in. Nash, No. 191 160 (Wyoming).					
27-29.........	$\frac{1}{2}$	22.83	16.96	1.0050	933.14
30-32.........	$\frac{1}{4}$	70.00	6.89	1.0000	573.79
24-26.........	$\frac{1}{8}$	92.78	0.77	1.0076	172.70
33-35.........	$\frac{1}{16}$	95.92	Not measurable.	1.0063	44.77
36-38.........	$\frac{1}{32}$	94.80	" "	1.0004	11.24
$\frac{3}{4}$-in. Nash, No. 133 225 (Hamburg).					
20...........	....	44.1	4.265	1.020	849.14
19...........	....	44.1	1.422	1.010	509.64
17...........	....	44.1	0.142	1.003	192.87
12...........	....	44.1	Not measurable.	1.000	50.73
6...........	....	44.1	" "	1.075	10.56
$\frac{5}{8}$-in. Trident, No. 23 178 (Wyoming).					
63-65.........	$\frac{1}{2}$	25.00	19.47	1.0004	926.78
66-68.........	$\frac{1}{4}$	66.67	7.96	0.9971	556.23
69-71.........	$\frac{1}{8}$	93.76	0.77	0.9938	173.52
72-74.........	$\frac{1}{16}$	95.09	Not measurable.	1.0027	44.57
75-78.........	$\frac{1}{32}$	87.52	" "	1.0446	10.80
$\frac{3}{4}$-in. Trident, No. 7 197*a* (Hamburg).					
12...........	....	44.1	8.103	1.000	1 170.40
11...........	....	44.1	1.706	1.000	524.44
10...........	....	44.1	0.284	0.996	201.58
5...........	....	44.1	Not measurable.	0.990	38.57
3...........	....	44.1	" "	1.010	11.36

obtained, curves were plotted for the $\frac{1}{2}$-in., $\frac{1}{4}$-in. and $\frac{1}{8}$-in. orifices, with the abscissas taken as the discharges in gallons per hour, and the ordinates as pressures in the service pipe. The curves were drawn on the theory that the discharge of a meter for a given orifice will vary as the square root of the pressure on the inlet side; and the actual discharge of a meter is compared with the discharge by the curve, for the given pressure on the inlet, to determine the loss of capacity by the resistances in the meter and its connections. The relation of the discharges by meters to the discharges by the plain pipe of the same approximate length as the separation of meter spuds, is given in Table No. 7.

A few years ago the water-works of Hamburg, under the direction of Herr O. Iben, conducted a series of tests upon three of the meters

represented in the Wyoming tests. The results of these tests, as furnished by a pamphlet issued by The Neptune Meter Company, of New York, and of the Wyoming tests, for the rates of discharge most nearly agreeing, are compared in Table No. 8.

The Trident and Nash meters, which came under Mr. Iben's observation, seem to have been not quite as accurate as those tested by the author, while the Lambert meter, tested abroad, gave very much better results in detail and as an average.

TABLE No. 9.—Average Errors of Registry.

Meter.	Wyoming test.	Hamburg test.
Trident	–0.73	+0.80
Nash	–0.38	–2.06
Lambert (Bee)	–5.11	–1.34

Three points are considered by Mr. Iben as essentials of a good water meter: (1) Sensitiveness or accuracy of registry at different rates of discharge; (2) capacity for a given size of meter, and (3) cost. To these should be added durability, without which any meter, however excellent it otherwise may be, will be a commercial failure. The meters in use in Germany are generally of the Siemens or inferential type, but much more complicated than the Columbia meter, represented in the Wyoming tests, which, excepting with the small streams of about 11 galls. per hour, gave very accurate results, but with a considerable reduction of pressure and capacity at the service pipe.

The use of water meters is much more general in Germany than in the United States. From a compilation of statistics of the waterworks of one hundred and twenty-one cities in Germany, including two in Holland, one in Denmark and one in Sweden,* the following information with reference to metered and unmetered water is taken.

In one hundred and eleven cities the total consumption of water for 1895 is stated as 445 158 552 cu. m. (117 611 000 000 galls.), of which quantity 220 158 552 cu. m. are metered, and 222 604 203 cu. m. are unmetered. It is not stated how the water is accounted for in the other ten cities consuming 31 542 777 cu. m. per year. Of these ten cities all excepting Zurich, Magdeburg and Leipsic are of small individual population. So far as the statistics indicate, about half the

* Statistische Zusammenstellung der Betriebs-Ergebnisse von Wasserwerken, Munich, 1895.

TABLE No. 10.—PERCENTAGE LOSSES OF HEAD BY METERS.

WYOMING.			BOSTON.		
Meter.	Gallons per hour.	Per cent. loss of head.	Meter.	Gallons per hour.	Per cent. loss of head.
⅝-in. Crown……. ½-in. connections.	872.8	83.90	¾-in. Crown……. ¾-in. connections.	1032.2	40.48
	546.2	16.79		448.8	7.32
	172.7	1.10		184.0	3.30
⅝-in. Worthington ½-in. connections.	828.3	83.81	¾-in. Worthington ¾-in. connections.	1050.2	38.10
	531.3	16.58		444.3	7.14
	172.2	1.18		193.0	4.25
⅝-in. Union……. ½-in. connections.	940.9	72.11	¾-in. Union……. ¾-in. connections.	1095.1	17.65
	581.9	8.20		435.3	4.17
	178.0	0.88		175.0	2.27
¾-in. Hersey…… ¾-in. connections.	913.5	74.38	¾-in. Hersey…… ¾-in. connections.	973.9	52.17
	559.9	11.85		453.3	6.25
	172.6	1.10		188.5	2.22
⅝-in. Empire…… ½-in. connections.	746.6	84.84	¾-in. Empire…… ¾-in. connections.	1081.6	27.03
	503.9	14.65		439.8	2.44
	167.4	0.82		184.0	4.44
WYOMING.			HAMBURG.		
⅝-in. Lambert….. ½-in. connections.	911.3	76.59	¾-in. Lambert….. ¾-in. connections.	834.3	17.41
	560.6	12.19		511.2	6.45
	173.0	1.17		194.2	0.97
⅝-in. Trident…… ½-in. connections.	926.8	77.87	¾-in. Trident…… ¾-in. connections.	1170.4	18.37
	556.2	11.94		524.4	3.87
	173.5	0.82		201.6	0.64
⅝-in. Nash……… ½-in. connections.	933.1	74.29	¾-in. Nash……… ¾-in. connections.	849.1	9.67
	573.8	9.85		509.6	3.22
	172.7	0.83		192.9	0.32

total consumption of water in the cities of Germany is metered, and by a device which will not compare in accuracy of measurement with the displacement water meters made and used in the United States.

In the London water-works different practices are followed by the several companies.* The New River Company meters all water supplied to large manufacturers and railway companies, the water used for street sprinkling, and sometimes the water for sewer flushing, amounting in all to 22.76% of the whole quantity supplied. The West Middlesex Company does not regularly meter any part of its supply. The Southwark and Vauxhall Company meters 18.87% of all the water it furnishes. The Chelsea Company meters all water supplied to the modern office and flat buildings, representing 23.6% of the total supply. The Lambeth Company meters 11% of its total supply. The East London Company meters 19.8% of its total supply. The Grand Junction Company meters a very small part (about 1%) of the water supplied, and the Kent Works has meters on 16.43% of all its services. In some examples the water is metered to a district through the

* Report of Royal Commission on Metropolitan Water Supply, London, 1893.

Deacon waste detectors furnished with recording apparatus. The intermittent supply to tanks, by the older practice of furnishing water to houses in London, in many instances renders meters less necessary than in the wholly open or undefended services in cities of the United States.

For purposes of comparison the meters tested, both at Boston and Hamburg, and by the author, are brought together in Table No. 10. In comparing the losses of head in these tests, it should be noted that at Boston and Hamburg all were $\frac{3}{4}$-in. meters with $\frac{3}{4}$-in. connections, while the Wyoming meters (excepting the Hersey) were all $\frac{5}{8}$-in., with standard $\frac{1}{2}$-in. connections.

The $\frac{1}{2}$-in. connection is actually $\frac{9}{16}$ in. in diameter, while the $\frac{3}{4}$-in. connection is actually $\frac{13}{16}$ in. in diameter; and assuming the loss of head, *i. e.*, the resistance by meter, to vary nearly as V^2, then the losses of head by the author's tests are with few exceptions uniformly lower than the losses reported for the Boston and Hamburg tests. Considering only the meters used in the Boston and Wyoming tests, it is possible that the latter may contain better proportions and workmanship than meters from the same manufacturers ten years ago.

Durability of Water Meters.

By way of showing the steady reputation which the Worthington water meter has sustained through a long history of actual service in many water-works, the Wyoming tests of $\frac{5}{8}$-in. meter No. 100 020 are compared with the Boston test of $\frac{3}{4}$-in. meter No. 5 990, and the San Francisco test of $\frac{5}{8}$-in. meter No. 26 737.*

TABLE No. 11.—Comparison of Three Worthington Meters.

Meter.	Diameter, of orifice, in inches.	Pressure, in pounds.	Ratio of tank to meter.	Discharge, gallons per hour.
$\frac{5}{8}$-in. meter, No. 100 020, tested at Wyoming, 1898	$\frac{1}{2}$	29.66	1.0089	828.27
	$\frac{1}{4}$	65.00	1.0089	531.30
	$\frac{1}{8}$	92.47	0.9885	172.25
	$\frac{1}{16}$	98.36	0.9933	45.34
	$\frac{1}{32}$	87.77	0.9064	10.82
$\frac{3}{4}$-in. meter, No. 5 990, tested at Boston, 1887–88	$\frac{1}{2}$	21.00	0.9974	1 050.19
	$\frac{1}{4}$	42.00	0.9810	444.31
	0.15	47.00	0.9847	192.98
	0.05	46.00	0.8848	22.89
	0.03	47.00	0.9466	8.98
$\frac{5}{8}$-in. meter, No. 26 737, tested at San Francisco, 1884	....	18.79	1.0138	742.20
	....	23.13	0.9958	444.00
	....	25.00	0.9815	194.00
	....	25.30	0.9519	52.20
	....	25.37	0.9200	10.80

* Ross E. Browne, "Water Meters." Van Nostrand Scientific Series, No. 81, p. 47.

The principle of the Worthington meter is such that it was a perfected machine in its original conception, and no improvements were possible, excepting as they related to materials of construction and proportion of parts. It was a characteristic of the late Henry R. Worthington, M. Am. Soc. C. E., that all his inventions were perfected when they took form in his great mind.

Upon comparing the errors of these three meters, widely separated in numbers and time of construction, it appears that the earlier meters were nearly as accurate as those of to-day.

TABLE No. 12.—Errors of Registry.

Meter.	Error.		
	Maximum.	Minimum.	Average.
Worthington, No. 100 020	+10.32	+0.67	+2.08
Worthington, No. 5 990	+13.02	−0.26	+4.48
Worthington, No. 26 737	+ 8.70	+0.42	+2.94

Considering the durability of water meters, the records of many water departments will show that some meters have been in service for many years and have given no serious trouble. How well these old meters are accounting for the water passing through them can be known only by removing them from the service pipes and testing them, or by providing facilities for testing them in the line of pipe. Very little information is forthcoming upon the accuracy of water meters after reasonable wear, but, so far as the author's experience has gone, this is a feature that deserves more serious consideration than seems to have been given to it thus far.

In order to obtain information on the wearing properties of water meters, a city water department took six $\frac{5}{8}$-in. meters from stock, and submitted them to the tests detailed in Table No. 13.

All these meters were obtained from well-known manufacturers, and those which passed the test successfully completed a performance quite the equivalent of 20 to 40 years in an ordinary domestic service pipe.

Meters "B," "C," "D," "E" and "F" were run beyond their rated capacity, and failure under these conditions was more likely to

TABLE No. 13.

Designation of meters.	Type of meter.	Days of service.	Cubic feet passed.	Average gallons per hour.	Remarks.
"A".........	Inferential	16	29 974	583.9	Failed to register on 16th day.
"B".........	Disc	3	11 260	1 169.9	Failed to register. Disc cracked on 3d day.
"C".........	Disc	41	204 218	1 552.5	Meter in serviceable condition at end of trial.
"D".........	Disc	25	111 362	1 388.4	Stem of disc ball broken on 25th day.
"E".........	Disc	40	202 276	1 576.2	Meter in serviceable condition at end of trial.
"F".........	Disc	45	200 000	1 385.3	Meter in serviceable condition at end of trial.

occur than if they had been operated for twice the length of time at half the stated rate of delivery. The performance of meters "C," "E" and "F" is marvelous, and should convince any water department about to adopt meters that a well-made meter is almost as durable as a stop-valve or piece of cast-iron pipe.

An examination of the records in detail of meters "C," "E" and "F" indicates a very uniform operation from day to day throughout the whole period of time, and considering the enormous number of pulsations of the discs (from 63 000 000 to 90 000 000) required to pass the amount of water credited to these meters, one cannot fail to be impressed with the performance of these simple little machines, which seldom excite our admiration, and sometimes come in for severe condemnation when one's water bill happens to exceed his expectations.

In connection with other experimental work the author recently had occasion to test two 3-in. hot-water Worthington meters for the Cincinnati Water Department. These meters were used with water at 190° Fahr., of the natural consistency of the Ohio River, between July, 1897, and April, 1898. The back pressure on the meters was about 105 lbs. during service, and the rate of operation quite uniform from day to day, averaging 180 cu. ft. per hour. The results of these tests, at different periods in the service of the meters, indicate how rapidly they depreciated with hot Ohio River water. The pistons and cylinders were of brass, and the meters were constructed and reconstructed for the special service in which they were used.

TABLE No. 14.

3-In. Worthington Meter, No. 72 088.

3-In. Connections. Brass Pistons and Sleeves for Hot Water.

Meter reading.	Cubic feet for interval.	Ratio of tank to meter.	Error of meter. Per cent.
112 335	......	1.0914	− 8.37
114 952	2 617	1.0958	− 8.74
139 484	24 532	1.1064	− 9.62
167 897	28 413	1.1146	−10.28
198 987	31 090	1.1418	−12.38
202 564	3 577	1.1831	−15.48
3-In. Worthington Meter, No. 70 577.			
3-in. Connections. Brass Pistons and Sleeves for Hot Water. (New.)			
3 652	......	1.0184	− 1.82
35 403	31 751	1.0309	− 3.00
61 256	25 853	1.0546	− 5.18
72 237	10 981	1.0729	− 6.80
3-In. Worthington Meter, No. 72 088. (Rebuilt.)			
0 000	......	1.0625	− 5.88
14 840	14 840	1.1226	−10.92
18 209	3 369	1.1398	−12.27
3-In. Worthington Meter, No. 72 088. (Again rebuilt.)			
1 355	......	0.999	+ 0.10
17 480	16 125	1.0133	− 1.31

The wear of meters with water at normal temperature, free from sand or other material which will cut the working parts, should be much less than with hot water containing at times much sand and mud in suspension, but the wear and reduced accuracy of water meters when used for a length of time, or after a reasonable service, is a matter to which little attention seems to have been given. Some unofficial reports have come to the author indicating that certain meters have passed enormous quantities of water without evidence of wear or reduced accuracy of measurement, but the water meter is a working machine, and, like all other machines, must be subject to wear, and, unlike most other machines, is not usually situated so as to admit of frequent examination and adjustment to compensate for wear. The author inclines to the opinion that the rate of wear and reduced accuracy of measurement will conform roughly to curves such as are indicated by Fig. 3 for the hot-water Worthington meters. The curve, of course, is to be fitted by experiment to each type, and perhaps each make of meter, and the water with which it is working.

In Fig. 3 the ordinates represent the percentage of delivery of the meter in excess of the registered amounts, or the percentage of water by tank measurement to the registry of the meter, less 100. In these experiments from 20 to 25 cu. ft. of water were drawn into the measuring tank, and the net weight of the contents of the tank was reduced to cubic feet for the observed temperature of the water as it passed through the meter.

If the author's theory is tenable, then meter manufacturers could furnish their customers with diagrams to be used from time to time in

DIAGRAM SHOWING RATE OF WEAR OF 3 IN. WORTHINGTON HOT-WATER METERS AT THE HUNT STREET PUMPING STATION, CINCINNATI, OHIO, WATER-WORKS. 1897-98.

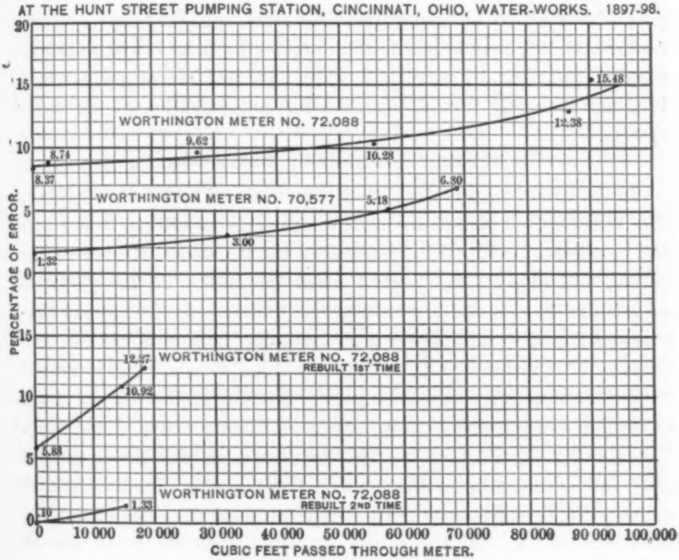


FIG. 3.

correcting the meter record, to obtain the true discharge or delivery of water. If a meter thus is fairly accurate when started, and in error —2% after 50 000 cu. ft., or some other quantity, has been passed through it, and out — 4 or — 5% after 100 000 cu. ft. has been passed through it, this diagram will furnish the proper factor by which to multiply the meter record at any period of its useful history.

This brings up the consideration of the maximum average error allowable in water meters. Conferences with several meter manufac-

turers indicate that in their opinion a meter is safe to use until the error reaches 7%, but there can be no doubt that there are in daily use many meters in which the average error is much greater than 7 per cent. Certain meters in these tests have average errors of more than 7%, and with meters which have been long in service, with no complaints as to stoppage or interference with the supply of water, the error, in many instances, as indicated by the author's experience, will be found to be much more than this modest figure. If 7% is regarded generally as the maximum allowable error, then thousands of meters now in use in all probability should be replaced by new meters, a proposition which all meter manufacturers doubtless will approve. An error of 10% may be admissible, provided it is known and the registry therefor can be corrected, while admitted errors greater than 10% unfortunately furnish material for condemnation of the meter system.

Construction Features of Water Meters.

In the rotary meters the pistons are made of vulcanized rubber. The Worthington pistons are made of drawn-brass tubing, with a central cast-brass head. This head unites the two tubes which form the piston, and receives the impact when the motion of the piston is arrested at the end of the stroke by the buffers. In the Crown, Empire and Union Rotary meters, the piston box or case is made of fine bronze. The piston box in the Hersey meter is made of vulcanized rubber, and the top and bottom plates which close the box are made of bronze and covered with a coating of rubber about $\frac{1}{16}$ in. thick. The working parts (excepting the gear-train) in this meter present only rubber surfaces to the action of the water. In all the disc meters, the discs are made of vulcanized rubber. In some meters the discs are flat, in others concave. If either form has an advantage over the other, the fact is not apparent to the author. The buffers of the Worthington meter are made of vulcanized rubber; in fact, this material forms such an important feature of water meters that in the Union Rotary and Columbia meters, even the gear-trains are made of vulcanized rubber; while in the Pittsburg meters, the first spindle of the gear-train turns in a vulcanized rubber bushing. The two large elliptical gears which connect the two pistons of the Union Rotary meter are made of vulcanized rubber, while the eccentric moving piston of the Empire meter is guided by a vulcanized rubber pin

which projects from its under side into a chamber in the lower cap of the piston box and impinges against a bronze friction roller.

With the exception of the Worthington, Union Rotary and Columbia, all the meters have bronze gear-trains, with cut or pressed wheels and pinions. The Worthington main gear is a single brass ratchet or crown wheel actuated by a pawl which is moved forward one tooth or more for each complete motion of the two pistons. In all the meters the internal screws are of brass. The disc case or box in all the disc meters examined is made of bronze. In the Trident meter the two sections of the disc box are united with a snap joint. In the Standard meter this snap joint is supplemented by screws, and in all others, excepting the Nash, the disc box is made up with screws. The bottom of the Nash disc box is held in place by friction, until the box is screwed down on the bottom part of the meter case. In the new form of Pittsburg meter the disc box forms a part of the meter case.

The bolts and nuts of the Trident, Hersey, Hersey Disc, Niagara and Pittsburg meters are of iron and galvanized; in all other meters, excepting the Worthington, the bolts are of iron with brass nuts. The Worthington meter case is put together with iron tap bolts.

Screens are provided in all the National meters to intercept solid particles in the water more than $\frac{1}{8}$ in. in diameter. The same result is accomplished in the Hersey Disc meter by the narrow annular space between the meter case and disc box through which the water passes before it reaches the disc box. In the Trident meter a strip of thin brass is attached at one end to the inside of the meter case, and extends partially around the disc box. This strip of brass is narrower than the chamber in the meter case and forms with the case a thin curved slot through which the water must pass before it enters the disc box. This device acts as a perfect interceptor of large solid particles which might enter the meter and interfere with its operation. No provision in the other meters to intercept floating solid matter was noticed by the author; but it is good practice with all meters to place a fish-trap or screen in the service pipe near the inlet connection, because such traps are more convenient to open and clean than is the meter itself.

Some complaint has been made of the discs of disc meters breaking under high pressures. If experience has demonstrated this to be an inherent defect of this type of meter, the difficulty might be

remedied by thickening the disc at the center and tapering it toward the edge. To do this, however, will require the sacrifice of a part of the ball-bearing surface or arc of vibration, which perhaps the meter manufacturers might consider a greater evil than the occasional breaking of the discs under high pressures. In the Nash meter the disc is strengthened by a steel wire, embedded in the rubber near the edge of the disc.

In these experiments the disc meters were frequently operated under pressures of 95 to 100 lbs. on the inlet side, and, to test the strength of the discs, this full head was often turned on the meter as suddenly as the cock in the supply pipe could be opened, with no evidence of injury to any meter which the author examined.

Frost bottoms are provided in the Trident and in the new form of the Pittsburg meters. These are of cast iron, inexpensive and easily replaced should an accident happen to the meter by the freezing of water in it. In other meters the top or bottom piece of the meter case is made of cast iron, which is expected by the manufacturers to break if the meter should freeze.

With one or two exceptions, all the meters examined were well built, with a nice fitting of all parts, and neat, legible dials. The meters generally throughout indicate the highest class of workmanship, and a careful consideration for the two essential features of a water meter, viz., accuracy of measurement and durability.

A function of the disc meter, which the author has not heretofore seen mentioned, is its capacity as a leak detector. All the disc meters which were placed in the line of the domestic service pipe, where the tests were conducted, maintained a continual vibration, which could be detected on the second floor of the building; while on closing a stop-cock in the discharge pipe near the outlet of the meter, the vibration ceased. An investigation of the cause of this continual and regular pulsation of the meter led to the discovery of trifling leaks in two taps which before had passed unnoticed. Upon timing the Nash meter under this condition, it was found that the vibrations of the disc were exactly four per second. The leaks were too small to be registered by the meter, and the only evidence it gave of their existence was the gentle vibration of the disc on its ball-bearing and the tapping of the driving pin against the guide or driving arm of the gear-train. After the discovery of this new feature in the disc meter,

several were connected one by one in the service pipe with similar results. If this rocking of the disc on its bearing with streams so small as to be unmeasurable is a common property of all disc meters, then they have an advantage over all other forms of meter, viz., of imparting knowledge of leaks in the domestic plumbing which otherwise might escape detection.

Revolutions of Pistons or Discs per Cubic Foot of Water.

After the several tests were made, all the meters were taken apart and carefully measured for water displacement per revolution of piston or disc, and the revolutions of piston or disc, and by gear-train, computed per cubic foot of water registered. For the piston meters this was determined by direct measurement of the working parts, while for the disc meters the displacement per revolution was obtained by carefully waxing all openings and filling with water the disc box with the disc in it. From the weight and temperature of the water, the net volume of the disc box was calculated. In several instances this result was checked from careful measurement of the disc and box. In the Columbia meter the revolutions per cubic foot of water discharged were calculated from the gear-train alone.

TABLE No. 15.—Revolutions of Pistons per Cubic Foot.

Meter.	Cubic inches, displacement per revolution.	Revolutions, by piston displacement.	Revolutions, by gear-train,	Percentage of slip allowed.
	Piston Meters.			
$\frac{5}{8}$-in. Worthington	56.544	30.56	30.00	1.83
$\frac{5}{8}$-in. Crown	10.600	163.03	163.89	None.
$\frac{3}{4}$-in. Hersey	15.750	109.71	109.37	None.
$\frac{5}{8}$-in. Empire	6.359	271.72	268.94	1.03
$\frac{5}{8}$-in. Union Rotary	17.360	99.54	98.65	0.90
	Disc Meters.			
$\frac{5}{8}$-in. Nash	3.869	446.63	446.75	None.
$\frac{5}{8}$-in. Hersey	5.415	319.12	316.18	0.92
$\frac{5}{8}$-in. Trident	4.770	362.32	358.40	1.08
$\frac{5}{8}$-in. Pittsburg, 8 011	5.740	301.06	295.78	1.76
$\frac{5}{8}$-in. Pittsburg, 10 798	5.876	294.10	289.06	1.72
$\frac{5}{8}$-in. Niagara	6.285	274.95	268.75	2.26
$\frac{5}{8}$-in. Standard	4.764	362.70	348.21	4.00
$\frac{5}{8}$-in. Lambert	5.633	306.75	302.40	1.42
	Inferential Meter.			
$\frac{5}{8}$-in. Columbia	......	......	800.00	....

Some objection may be raised to the general crudeness of the apparatus used in the author's tests, but originally only two questions

were presented in connection with the introduction of water meters by his village: (1) The relative accuracy under the same conditions of pressure and water delivery of the cheaper disc meters when compared with the piston meters, and (2) the relative value of both types of meters when operated with widely varying streams of water. These questions the author believes have been answered by the tests.

The conditions were alike for all meters, excepting the pressures in the supply pipe, and this variation of pressure was due to the circumstance that the street main from which the supply pipe to the meters was run was also a pumping main, and the variation of pressure in the supply pipe could only have been avoided by making all the tests at night under reservoir pressure. The author has no reason to believe that this variation of pressure on the inlet sides of the meters had any influence on their accuracy of measurement. Results were sought which would be fairly comparable with each other rather than precise in themselves; but this statement must be accepted as applying to the apparatus and not to the observations and deductions, which were carefully made and checked by at least two competent persons.

Prior to this investigation of water meters for domestic service, the author has several times been called upon in a professional capacity to examine and report upon some of the better known forms of meters, to settle disputes between water-works officials and dissatisfied water takers. From this experience, and the occasional use of water meters for test purposes, he has acquired a confidence in the reliability of these devices, which, unfortunately, is not generally shared by water-works engineers. This confidence has been strengthened by the present investigation to such an extent that he believes the use of water meters should become, at the earliest possible date, an essential feature of all water-works which pretend to conduct business upon modern enlightened principles.

DISCUSSION.

JOHN THOMSON, M. Am. Soc. C. E.—This paper, treating of a test of commercial apparatus, is of the kind that almost any member of the Society has material for at different periods of his experience, but the fact is, that few members take the trouble to prepare and submit such useful data. The author is therefore to be especially commended for its presentation. Mr. Thomson.

The speaker regards the apparatus described as adequate for such a test as the author desired to make, and believes that the illustration, Fig. 2, might well serve as a model for those who are not satisfied with the experience of others and desire to demonstrate for themselves, through the medium of a bench test. As a manufacturer, the speaker prefers the use of tanks which indicate the quantity by volume rather than by weight, as less time is required, variation due to temperature need not be regarded, there is less likelihood of errors of observation, and the sliding scale which is connected to the glass indicating tube may be graduated to denote directly the percentage of the total quantity discharged through the meter. Thus, if the meter indicates 9 cu. ft., and 10 cu. ft. are found in the tank, the scale would read 90%; or, if the meter indicated 10 cu. ft., and 11 cu. ft. were found in the tank, then the scale would read 110 per cent. This system of notation is believed to be preferable to expressing the error as plus or minus, or by the proportion of cubic feet or gallons.

The author specifies and carries through his tables a refinement which, in the speaker's judgment, in a test of this character, is "more nice than wise," namely, the calculation of the weight of the water due to its temperature. This is referred to, not to be hypercritical, but simply to suggest that future experimenters may safely neglect this detail, because no commensurate result is ordinarily derived. Thus, in Table No. 1, the greatest difference of temperature noted is 9°, equivalent to approximately 0.05 lb. per cubic foot, or less than $\frac{1}{10}$ of 1%, an error which is probably less than that of the platform scale used. There is, however, an element of variation due to changes of temperature, within ranges of, say, 15 to 25°, which may be taken into account, under certain conditions of operation, that is, the effect upon the displacing member of the meter when made of hard rubber, as the coefficient of expansion of hard rubber is different from that of brass or composition. Therefore, a relatively moderate change of temperature may affect considerably the registration of the meter at low rates of flow, increasing or decreasing, as the case may be, its sensibility, and in cases of extreme high temperature this may wreck the meter.

The author occasionally uses the term "accurate" where "sensibility" would seem to more clearly convey the intended meaning. A

Mr. Thomson. meter may have a more or less wide range of sensibility without affecting its general efficiency, or accuracy, as a commercial instrument. Then, too, the maintained sensibility of a meter is dependent largely upon the conditions of operation and the water which passes through it. In this connection it may be well to note that the foreign matter carried by the water described by the author is not calculated to improve the condition of an accurately constructed device. As a matter of fact, as frequently proved by practical use, all meters set where the water is charged with grit or silt ought to be fitted to operate with a much less degree of sensibility than where the water is pure. The reason for this is that when the parts are closely fitted the first effect of grit is to cause them to wedge, bind, cut and wear, usually producing by such automatic action a greater degree of clearance than if originally fitted with sufficient freedom to permit the particles to pass freely. The speaker, however, has quite given up the expectancy that this oft-repeated suggestion will receive much attention; as ordinarily the water-works superintendent or engineer, who undergoes a change of heart from the system of disposal at the discharging capacity of the faucet to that of paying by measurement, is then usually not content to gauge his *aqua pura* by units of cubic feet or gallons; he at once rises to the situation and would subdivide it by drops, as if it were liquefied oxygen or Scotch whiskey.

The matter of sensibility, however, is especially important, and should be considered, where meters are used in connection with tank service and the like, or where driblet flows are desired to be registered. In the disc type of meter, especially in the smaller sizes, the degree of sensibility obtainable is dependent upon the quality of the water, that is, whether pure or otherwise, the materials used in construction, the frictional resistance of the reducing gear-train and the degree of accuracy with which the disc and its casing are fitted. Suffice it to say that it is entirely feasible, and has frequently been carried out in practice, when required, to produce disc meters of the $\frac{5}{8}$-in. and $\frac{3}{4}$-in. sizes that will indicate from 50 to 75% of the quantity discharged when the rate of flow is as low as $\frac{1}{10}$ cu. ft. per hour; but, for the great majority of conditions, such refinement would be as much out of place as to nickel-plate a sand pump or a soldering iron.

The comparison of the Wyoming and Hamburg tests, Table No. 8, is interesting as showing the wide range in rate of flow, from 20 to 1 up to 119 to 1.

Regarding the matter of obstruction, or loss of head due to the meter, this, in many cases, is of but little practical importance. The general application of meters, with the resultant saving of wasteful flow, has the result of increasing the dynamic head. This is a well-known fact, but is not infrequently overlooked by experimenters and theorists. In so far as meters of the disc type are concerned, all of those now on the

market could readily be modified to secure a delivery almost equal to that of the pipe, but this would be bad for some of the meters. Nearly all the differences of obstruction in the several disc meters tested by the author are due, not to differences of mechanical operation, but to variations in the form and construction of the water-ways and ports, and the screens or other analogous means for preventing material of large caliber from entering the measuring chamber. Strange as it may seem to some, the fact that a meter may be designed so as to be very free in its delivery may, in some instances, be an element of danger, in that it will more quickly result in the destruction of the meter. The reason for this is that it is only in rare instances that meters are selected, for the service they are to perform, on the basis of their capacity. The almost universal practice is to simply select a meter, the nominal size of which corresponds to that of the pipe to which it is to be attached. In other words, pipe-fitters and political appointees are not always engineers, and a meter, to be successful commercially, must be designed to meet the conditions just intimated. Mr. Thomson.

In fine, the nub of this obstruction matter may be thus illustrated: First, assume a water supply in which the quantity and the head are just sufficient to furnish a certain number of services, and that these services are to be metered. Then, if the meters themselves caused an obstruction to the flow greater than that of the pipe which they displaced, the desired supply, obviously, could not be obtained. This would be a condition where there might be justification for eliminating loss of head to the last place of decimals. But, second, no such condition has to be met in regular practice, this kind of "practice" being where meters are set to restrict waste. In such cases, whether the coefficient of obstruction of the meter is a full number or a fraction thereof is of but little consequence, in that the quantity saved will restore a greater degree of the dynamic head than is absorbed in the measurement of the quantity used. This fact has been proven so completely and so frequently that an excuse would be made for bringing it up here were it not a theme which, dear to the hearts of many, like the problem of squaring the circle or soliloquizing on a new spacial dimension, will not down. The hardship of such considerations is not to the manufacturers, who may be assumed to know something of the necessary requirements, but to the investigator whose mind may thus be clouded and perplexed by attempting to assimilate data which are largely nonsensical and useless.

The method and means which the author used for ascertaining the obstruction produced by the meters—the introduction of a section of service pipe corresponding in length with that of the meters—the speaker regards as most excellent, he having used this for similar tests with the utmost satisfaction; but he fails to see why a comparison of the discharge of the meter should have been made with curves of theo-

Mr. Thomson. retical discharge, when, if the speaker understands the data correctly, a comparison should have been made directly between the discharge of the meters and that of the pipe. Referring to Table No. 6, and taking the discharge in gallons per hour, through the $\frac{1}{2}$-in. orifice, the average of the first five quantities in the right-hand column is 961.49 galls. Then, taking five of the disc meters tested, as in Table No. 7, the maximum average is found to be 906.21 galls., or, assuming the pipe as unity, as it is for this purpose, and the static pressure equal in both cases, then the relative capacity of the meter is 94.2%; that is, when the maximum discharge is determined, both in the meters and in the pipe, by the same static head and the same sharp-edged diaphragm having a perforation $\frac{1}{2}$ in. in diameter.

Supplementing the remark about the test by the Boston Water Board, it may be of interest to note that no meters of the disc type were then on the market; and that since then, or in about eleven years, fully 250 000 meters of this type have been made and sold by American manufacturers. Had it not been for archaic conservatism this number would easily have been doubled. The future, however, bids fair to correct this in full measure. The speaker, therefore, takes the liberty of asserting that the question of type is not a matter yet to be demonstrated; as the disc type, to quote, by adoption, the author's own words, has already "become the standard of water meters for domestic uses." Therefore, in this regard, the only feature of consequence, which for several years has received the close consideration of engineers familiar with the state of the art, has been the differentiation of the type to its lowest terms as respects price, accuracy, general efficiency and cost of maintenance.

Regarding the relative importance of durability: This is by far the most important element to be considered. It is taken for granted that the author includes in this general term convenience of examination, maintained accuracy, immunity from stoppages and cost of maintenance. A rather conclusive proof of the durability and continuity of performance of meters of the disc type is furnished by the author himself, in that the four Trident meters specified by their serial numbers in Table No. 1 were shipped to Wyoming in September, 1896, where they had, it is understood, been placed in service, and that at least one of them, No. 23176, had passed, as the speaker is informed by the author, nearly 25 000 cu. ft. of water prior to removing it for this bench test. Moreover, the original calibration, as recorded at the factory, corresponds closely, at maximum flows, with those given in the table. The sensibility, however, shows considerable deterioration. Nevertheless, if the author can say that all these meters had been continuously in service, then their performance on sensibility flows may be regarded as highly creditable, especially so, if they were not pulled apart and cleaned out prior to the test, so as to put them in proper condition for a comparative

demonstration with new meters. Moreover, these meters, as originally furnished, were provided with extension dials about 3 ft. in height. It would also be interesting to know, in this connection, whether these meters were tested with or without the extensions. If without the extensions, and the meters were subsequently set in service with the extensions, then the bench test for sensibility would have but little value, as the extra friction caused by the additional parts materially reduces the sensibility of all meters arranged in this manner. Mr. Thomson.

The experiment of turning on the full inlet pressure suddenly "to test the strength of the disc," is without significance; having, as a demonstration, no practical value whatever. This statement is made on

Destructive Durability Test of a 5/8 In. Disc Water Meter.

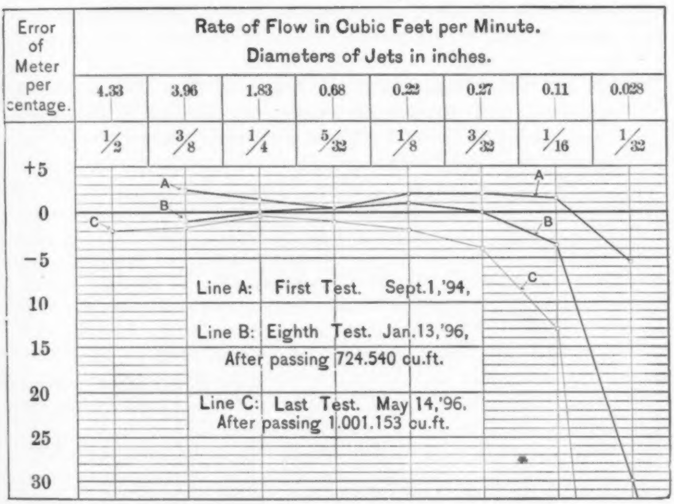


FIG. 4.

the presumption that the meters were tested in the circuit as shown in Fig. 2. The intention of this experiment, however, was most laudable; for one of the most serious defects of the disc system is the liability of the disc-piston to break, especially when made of hard rubber. Such failures, however, are quite as likely to occur when the pressure is 40 or 50 lbs. to the square inch as when it is 150 or 200 lbs. Fractures of disc-pistons are not due merely to excessive pressure, but are caused by such a hydraulic condition as will produce very high velocity of flow through the disc-chamber, thus operating the disc at a much higher rate of speed than that for which it is properly adapted, and hence in-

Mr. Thomson. ducing rapid wear of the ball and socket, the periphery of which, in nearly all the meters cited, will permit the disc to jam between the wall of its casing and the diaphragm, which results in its ruin. It would appear to be evident, therefore, that a mere bench test is of but little value for ascertaining the relative durability of disc meters, in respect to the endurance of the discs, and that for this detail the only test entitled to any importance is to operate the meters under very high rates of delivery, either continuously or intermittently, until large volumes of water have been discharged. The consequence of such a trial will be either to smash the disc or show by its appearance its ability to stand severe punishment. As bearing upon this question, the results of some experiments of the nature indicated, made by Mr. A. W. F. Brown, Water Registrar of Fitchburg, Mass., are shown in Table No. 16, and in Fig. 4, which the speaker has prepared from original data furnished by Mr. Brown.

TABLE No. 16.—DURABILITY TEST OF A $\frac{5}{8}$-IN. DISC WATER METER, PREPARED FROM RECORDS FURNISHED BY MR. A. W. F. BROWN, WATER REGISTRAR, FITCHBURG, MASS., WHO CONDUCTED AND CONTROLLED THE PERFORMANCE.

(This trial was undertaken with the intention and expectancy of destroying the meters.)

Dates.	Quantity passed, in cubic feet.	Rate of flow, in cubic feet per minute.	Diameter of Jets, in Inches, and Percentage of Error, Plus or Minus.						
			$\frac{3}{8}$	$\frac{1}{4}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{3}{32}$	$\frac{1}{16}$	$\frac{1}{32}$
Sept. 1, 1894..	....	....	+2.5	+2.0	+0.5	+2.0	+2.0	+ 1.5	− 5.5
Sept. 19, 1894..	100 772	4.0	+1.0	+0.1	+0.5	+2.0	+1.0	− 2.0	−32.0
Oct. 3, 1894..	205 145	6.0	0.0	+0.5	+1.0	+1.0	−2.0	− 7.0	−33.0
Jan. 28, 1895..	327 888	1.5	+1.0	+0.5	+1.0	+1.0	+2.0	− 4.0	−30.0
April 18, 1895..	409 037	1.5	+2.0	+2.0	+2.0	+1.0	0.0	− 3.5	−30.0
Oct. 23, 1895..	631 761	1.5	0.0	−0.8	+1.5	−0.5	−1.0	− 5.0	−33.0
Jan. 13, 1896..	724 570	1.5	−1.0	0.0	+0.5	+1.0	0.0	− 3.5	−30.0
April 25, 1896..	906 229	1.5	−0.5	−0.5	0.0	−0.5	−3.0	− 9.5	......
May 14, 1896..	1 001 153	4.5	−1.5	−0.5	+1.0	−2.0	−4.0	−13.0	......
Maximum errors..................			+2.5	+2.0	+2.0	+2.0	−5.0	−13.0	−100.0
Greatest variations..............			4.0	2.8	3.0	4.0	6.0	14.5	94.5
Mean errors......................			1.0	0.8	0.9	1.2	1.6	5.4	27.5

Mean error of all service flows, from $\frac{1}{8}$-in. up.................................. 1.1%

Quantity in United States gallons.................... .... 7 508 647
Revolutions of disc.. 358 873 235
Duration of trial, about 1 year and 8 months.
Equivalent mechanical service, assuming daily consumption of 250 galls..... 113 years.

Concurrent with the above, another $\frac{5}{8}$-in. Disc Meter was also tested until 817 561 cu. ft. had been delivered; the last 78 000 ft. being at the rate of 6.5 cu. ft. a minute under 150 lbs. pressure, finally smashing the disc, which, after passing about 740 000 cu. ft., had stood for 27 300 000 revolutions, at the rate of 38 nutations a second.

Mr. Thomson.

Regarding the author's theory as to rate of wear, as illustrated in the diagram, Fig. 3, in the speaker's judgment this is entirely untenable, and is not even properly applicable in the instance of the Worthington meter, to which the diagram refers, because a 3-in. meter of this type for the duty mentioned, is only worked to about $\frac{1}{5}$ of its maximum capacity. Therefore, if fitted to give sufficiently accurate results at so low a flow, under the conditions mentioned, it will the sooner wear itself free. This example is not properly comparable with regular practice, and does not do justice to the enduring quality of this meter.

The author's clever use of the disc meter as a leak detector is a novelty. The speaker once used a very sensitive meter for the purpose mentioned, by removing the gear-train and substituting a delicately adjusted electric contact device, the circuit being closed and opened by the nutation of the disc. The wires were conducted to the desired place of observation and connected to a telegraphic sounder, the time interval between the "clicks" indicating the rate of flow and the quantity. The number of places of decimals to which it would indicate was never definitely ascertained, but its sensibility was so pronounced that it was promptly christened the "dew-drop" meter.

The observation made as to the desirability of information respecting the accuracy of water meters after a period of use is fully concurred in by the speaker, who believes that much valuable information could be contributed by various members of the Society if they would do so. This information is largely in the hands of purchasers, and can only be furnished by them. Private corporations, for various business reasons, rarely publish such records; while the records of municipal departments are usually not in form to be readily available. This condition is improving, however, and many engineers of public works and water supplies are now keeping close tab on this feature and also on the cost of maintenance.

In conclusion, the speaker ventures to remark that the fact that water meters in general perform as well as they do is to him a matter of surprise; for there is no machine, or instrument, bar none, from which so much is preliminarily exacted, and which receives so little attention once it is set in the dark corner of a cellar or vault. When the policy of legitimate use shall have been substituted for that of unlimited waste, then this compact, inexpensive, ever-vigilant monitor, when properly utilized, is capable of saving to taxpayers during every decade tens of millions of dollars' worth of needless construction.

Mr. Smith.

J. Waldo Smith, M. Am. Soc. C. E.—At this time, when cities so quickly grow beyond the capacity of a water supply, which, at the time it was acquired, was expected to last for half a century, and when economy in the use of water is such an important factor, any information which adds to the knowledge of water meters is a blessing to the water-works engineer.

Mr. Smith. Table No. 2 seems to the speaker to be misleading and liable to give an entirely wrong impression unless studied with great care. As he understands it, a straight arithmetical average of the errors has been made, as shown in Table No. 1, without regard to the range of flow between the different experiments. In other words, an insignificant part of the range of the meter has been given equal weight with the conditions of flow which cover nearly the whole of that range.

Had lower rates of flow been tried, say $\frac{1}{64}$-in. orifice, the maximum error might easily have been 60%, and the average error 20%, and still, as ordinarily used, all the meters would have been practically correct.

Take, for example, the curve of velocities in a float measurement. It would be manifestly erroneous to average a velocity taken close to the side of the flume, and representing a width of 0.5 ft., with those taken some distance out, and representing widths of several feet, unless each were multiplied by the width it covered.

By this way of figuring, a meter which would not register with the $\frac{1}{32}$-in. or $\frac{1}{16}$-in. orifice would show a very small average error, and one which registered only about 40% of flow with a $\frac{1}{32}$-in. orifice, and which was tested with but two additional flows, would show a very large average error, and would give the impression that the meter is of no value as a measure for water, while for all ordinary flows it is almost exactly correct. This is one of the places where an average is wrong and is entirely misleading.

For similar reasons the comparisons given in Tables Nos. 3 and 4 are not fair, for in the Wyoming tests of $\frac{5}{8}$-in. meters the minimum flow was at the rate of about 11 galls. per hour, while in the Boston tests of $\frac{3}{4}$-in. meters, which are of about double the capacity of $\frac{5}{8}$-in. meters, the minimum rate of flow was about $8\frac{1}{2}$ galls. per hour, which is evidently unfair to the Boston tests if compared by average error, as in Table No. 4, and the last column in this table does not mean anything.

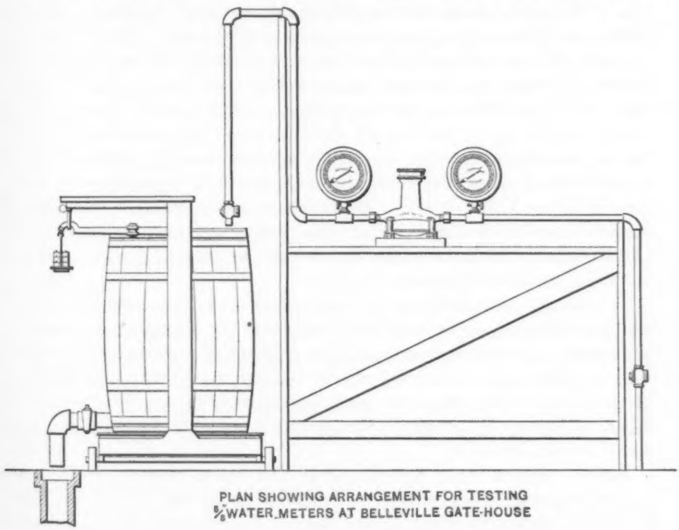
The last column of Table No. 5 gives the percentage of loss of head figured on the inlet pressure. Now, the loss of head is only indirectly a function of the inlet pressure, being rather a function of the rate of flow, and it is impracticable to compare tests of meters on this basis. The speaker regrets that this table is not in the form of rate of flow and loss of head.

The importance of the loss of head cannot be overestimated. Upon one hand the consumer usually objects to any appreciable lowering of the efficiency of his service pipe as a water carrier, and on the other hand the Water Department desires to set as small a meter as possible in order to reduce the expense. With meters showing a small loss of head, it is often possible to set meters of a smaller size than the service pipe, which would not be wise with meters showing a large loss of head. In reference to this, the speaker believes it is economy to put

the meter department in the hands of a competent engineer who is posted on the flow of water, and who will not always insist on setting a meter of the same size as the pipe when one much smaller is ample for the work, or *vice versa*. In the speaker's experience during the past year, a number of places have been found having 4-in. services where a 1-in. or $1\frac{1}{2}$-in. meter was ample to measure all the water used. Mr. Smith.

The speaker makes the same objection to Table No. 9 as to Table No. 4, and cannot see how a comparison can be made on the basis of average error, unless the tests are made at exactly the same rate of flow and the meters are of the same size.

In Table No. 10 the Wyoming, Hamburg and Boston tests are com-



PLAN SHOWING ARRANGEMENT FOR TESTING
$\frac{5}{8}$" WATER METERS AT BELLEVILLE GATE-HOUSE

FIG. 5.

pared by percentage loss of head. If the inlet pressure was the same in each case this might be possible, but with the inlet pressure varying in the different cases it is not practicable.

The speaker has never been able to make a satisfactory comparison in such cases as this without the aid of curves and diagrams, and regrets very much that these experiments have not been reduced to this form.

In regard to the curves of deterioration, as illustrated by the diagram of the Worthington meter, Fig. 3, the speaker is of the opinion that meters of the same make and using the same water would show deterioration curves widely different, and that such curves would not

Mr. Smith. be of any practical use unless the meter was run at a uniform rate, for the error of the meter depends on the rate of flow.

Aside from the foregoing the speaker regards the rest of the data and opinions presented as admirable. What is said in regard to the meter as a leak detector is entirely new, and should prove very useful. The speaker can say "Amen" most heartily to the author's closing remarks in regard to the general use of water meters, and he looks for the day when water will be sold entirely by meter measurement.

To compare the flow as measured by the meters with the total quantity pumped would be exceedingly difficult, on account of the many variable factors in the case. The slip of the pump and the leakage of the pipe system are usually unknown and variable quantities, and hence there is great uncertainty as to how much of the full quantity of water the meters fail to register. Possibly under a new order of things, when pipe systems can be divided into a number of parts, with each particular part of the system measured by one large Venturi meter, something in the line of Mr. Harlow's suggestion may be done; but at present the speaker does not see how it could be carried out. In a case in Burlington, Vt., some time ago, and which was reported to the New England Water-Works Association, a small district was entirely metered, and the leakage of the pipe system had been measured. On comparison it was found that the meters accounted for 90 or 91% of the total quantity supplied.

In view of the character of this paper and its probable value to water-works superintendents and engineers the speaker takes this opportunity to present in condensed form a set of experiments on small water meters made some years ago by the direction of Clemens Herschel, M. Am. Soc. C. E., Engineer and Superintendent of the East Jersey Water Company, in order to determine, if possible, the best meter for ordinary house service.

Seven meters were purchased in the open market without the manufacturers being aware of what was to be done with them. Four, the Union Rotary, Hersey Rotary, Crown and an experimental meter were of the rotary piston type, and three, the Thomson Bee, Hersey Disc and Trident, were disc meters.

The tests were all made in the Belleville gate house of the East Jersey Water Company. All the meters were first tested for accuracy. For test, a meter was set firmly in a horizontal position in a short line of ½-in. pipe which joined a 1-in. pipe connecting to one of the main 16-in. supply pipes, about 2 ft. up stream from the meter. On the down-stream side, the short piece of vertical pipe just over the measuring barrel was also 1 in. in diameter, and was terminated by a 1-in. stop cock. The rate of flow was varied by screwing plugs, bored with different-sized holes, into the stop cock, so that in all cases the 1-in. cock was open full during an experiment, the flow being throttled by

the plug. To regulate very small flows a ¼-in. pipe with a stop cock was attached to the 1-in. cock. Mr. Smith.

The measuring barrel was set on a Fairbanks standard platform scale and was perfectly tight. All weights were read to the nearest $\frac{1}{10}$ lb. The general arrangement is shown in Fig. 5.

On each side of the meter, and as near to it as practicable, a pressure gauge was attached to the ½-in. pipe, so as to observe the loss of head caused by the passage of water through the meter and its couplings. These gauges were frequently compared with each other, when under the same pressure, and were also rated on a Crosby gauge tester. Pressure was observed to the nearest $\frac{1}{10}$ lb.

The method of procedure in making a test was as follows:

Scale, with measuring barrel on, balanced, and weight recorded; reading of meter recorded; flow started, and time noted; reading of pressure gauges noted; after a sufficient quantity of water had passed for a good experiment, flow was stopped, time noted and water was weighed.

Except for the very small rates of flow, nothing less than 1 cu. ft. was passed through the meter for an experiment, and for the larger flows the quantity was from 2 to 5 cu. ft.

In the first set of accuracy tests, Fig. 6, about thirty experiments were made with each meter, and in the subsequent tests about twenty experiments.

The maximum pressure on the meters was from 65 to 68 lbs.

After being tested for accuracy, the meters were set up and run until their dials registered from 103 000 to 106 000 cu. ft., when they were again tested for accuracy.

The time required to register these quantities was from twenty-eight to thirty-five days. The rates of flow are given in Table No. 17.

TABLE No. 17.

Union Rotary..	0.043 cu. ft.	per second	= 19.5	galls.	per minute
Experimental..	.040	"	"	= 18.0	"	"
Trident.,......	.039	"	"	= 18.0	"	"
Thomson......	.039	"	"	= 18.0	"	"
Hersey Disc...	.039	"	"	= 18.0	"	"
Crown.........	.036	"	"	= 16.0	"	"
Hersey Rotary.	.034	"	"	= 15.0	"	"

The experimental meter failed after running twenty days and registering 70 000 cu. ft. The stoppage was due to the breaking of the rollers.

The meters were now tested for accuracy (Fig. 7), as in the first place, and then returned to their places, and run against time.

Mr. Smith. Where meters are in general use the consumption is said to be about 3 000 cu. ft. per family per year, which seems small. From the speaker's observations he would consider it safer to put the consumption at 10 000 cu. ft. per year in estimating the service of a $\frac{5}{8}$-in. meter.

In calculating the yearly service of meters, the speaker will assume that 100 000 cu. ft. is equal to 10 years' service.

Up to the end of the second durability test the meters had run as shown in Table No. 18.

TABLE No. 18.

Name of meter.	Total time run, in days.	Total quantity registered. Cubic feet.	Equivalent years' service on basis of 100 000 cu. ft. = 10 years' service.	Pressure maintained on up-stream side. Pounds.	Rate of flow. Cubic feet per second.	Remarks
Union Rotary....	73	266 000	26.6	51	0.042	
Experimental ...	......	....	......	......	......	Rollers broken.
Trident..........	77	267 000	26.7	46	0.040	
Thomson.........	77	264 000	26.4	50	.040	
Hersey Disc......	77	264 000	26.4	48	.040	
Crown...........	76	238 000	23.8	56	.036	
Hersey Rotary..	80	235 000	23.5	51	.034	

The meters were now tested the third time for accuracy (Fig. 8), and were then run against time as before, until they had registered the quantities given in Table No. 19, when they were again tested for accuracy, the results of which are shown by the curves in Fig. 9.

TABLE No. 19.

Name of meter.	Total time run, in days.	Total quantity registered. Cubic feet.	Equivalent years' service on basis of 100 000 cu. ft. = 10 years' service.	Pressure maintained on up-stream side, in pounds.	Rate of flow. Cubic feet per second.	Remarks.
Union Rotary...	103	377 000	37.7	....	0.042	
Experimental....	25	82 000	8.2	....	.038	Broken.
Trident..........	108	377 000	37.7	....	.040	
Thomson........	108	376 000	37.6	....	.040	
Hersey Disc......	108	371 000	37.1	....	.040	
Crown...........	106	325 000	32.5	....	.035	
Hersey Rotary..	112	327 000	32.7	....	.034	

They were now set in place and left standing under 65 lbs. pressure for four months, May 21st to Sept. 24th, 1895, and were then tried for

sensitiveness by turning the stop-cock in the discharge pipe of each until the meter just started, when the rate of flow was measured. The results are given in Table No. 20. Mr. Smith.

TABLE No. 20.—RATES OF FLOW AT WHICH METERS WOULD JUST BEGIN TO REGISTER, AFTER STANDING 4 MONTHS UNDER PRESSURE WITH NO WATER RUNNING THROUGH.

Name of meter.	Rate of flow. Cubic feet per second.	Rate of flow. Gallons per minute.
Union Rotary	0.00051	0.23
Crown	.00068	0.31
Hersey Rotary	.00126	0.57
Trident	.00047	0.21
Thomson	.00047	0.21
Hersey Disc	Played out, will not run.	

This test was not entirely satisfactory, although it is of some value in indicating to what extent the sensitiveness is affected by the meter standing still for a long time.

The five remaining meters were now set running as before, and at about the same rate.

Union: Continued to run until it was shut off, when it had registered 1 589 000 cu. ft.

Crown: Ran until shut off, and had registered 1 120 000 cu. ft.

Hersey Rotary: Stopped after registering 920 000 cu. ft., and was then completely worn out.

Trident: Continued to run without accident until shut off, when it had registered 1 644 000 cu. ft.

Thomson: After registering 711 100 cu. ft., stuck fast, but was repaired and started again, but stopped after registering a total of 932 000 cu. ft.

The total registration of the meters, the rate of flow, etc., up to the time each meter stopped or was shut off, is given in Table No. 21.

There is little doubt but that some or all of these meters would have stopped sooner if they had been run at a lower rate of flow, under a less head, or with roily water.

Up to the end of the test, no meter except the Thomson had been taken apart or had had any repairs whatever. During the entire period, however, the water was very clear, and contained little or no sediment.

After the test, as recorded, the meters were thrown to one side, and forgotten for about eighteen months. Two, the Trident and Crown, have recently been tested. At the time of this last test neither had received any particular care, nor had they been taken apart, repaired or renewed in any part.

The results of this last test are given in Table No. 22.

Mr. Smith.

TABLE No. 21.

Name of meter.	Total days run.	Total quantity registered. Cubic feet.	Equivalent years' service on basis of 100 000 cu. ft. = 10 years' supply.	Rate of Flow. Cubic feet per second.	Rate of Flow. Gallons per minute.	Remarks.
Union Rotary.	413	1 589 000	158.9	0.045	20.2	Shut off, but is still in running order.
Trident........	427	1 644 000	164.4	.045	20.2	Shut off, but is still in running order.
Thomson......	268	932 000	93.2	.040	18.0	Stopped. Also stopped after registering 711 000 cu. ft.
Crown........	406	1 120 600	112.0	.032	14.4	Shut off, but is still in running order.
Hersey Rotary	315	920 000	92.0	.035	15.7	Stopped. Worn out.

TABLE No. 22.

	Trident. Rate of flow, in cubic feet per second.	Trident. Percentage of flow registered.	Crown. Rate of flow, in cubic feet per second.	Crown. Percentage of flow registered.
Orifice full......	0.0604	98.8	0.0357	67.5
$\frac{1}{2}$-in..............	0.0455	98.8	0.0269	68.0
$\frac{3}{8}$-in..............	0.0376	98.5	0.0175	68.8
$\frac{1}{4}$-in..............	0.0185	98.6	0.0049	Will not run unless shaken.
$\frac{1}{8}$-in..............	0.0051	96.5		
$\frac{1}{16}$-in..............	0.0016	40.0		
Will just run with $\frac{1}{16}$-in. orifice, and will not move with $\frac{1}{32}$-in. orifice.				

The record of each of these meters is phenomenal. The Trident, between flows of 2.3 and 27.0 galls. per minute, gives an average accuracy of 98.2%, and is sensitive to a flow of 0.7 gall. per minute. The Crown does not give quite such good results, but in justice to this meter and other similar rotary meters, it should be stated that this form of meter can be restored to nearly its original accuracy and sensitiveness by turning down the case. In the present test it was desired to see the result of running the meters to destruction, without doing anything to them.

On examination, both of these meters seemed to be in fair condition, and with a few repairs would have stood a long run before failing. It would be interesting to repair these meters and see how much water they would pass before failing, also how nearly they could be restored to something like their original sensitiveness and accuracy at small expense.

Mr. Smith.

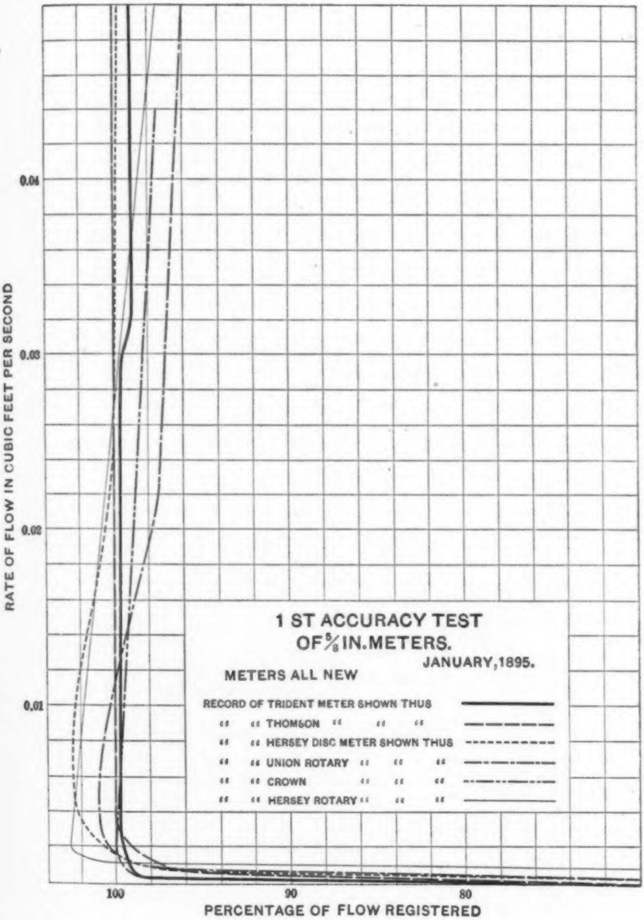


FIG. 6.

Mr. Smith.

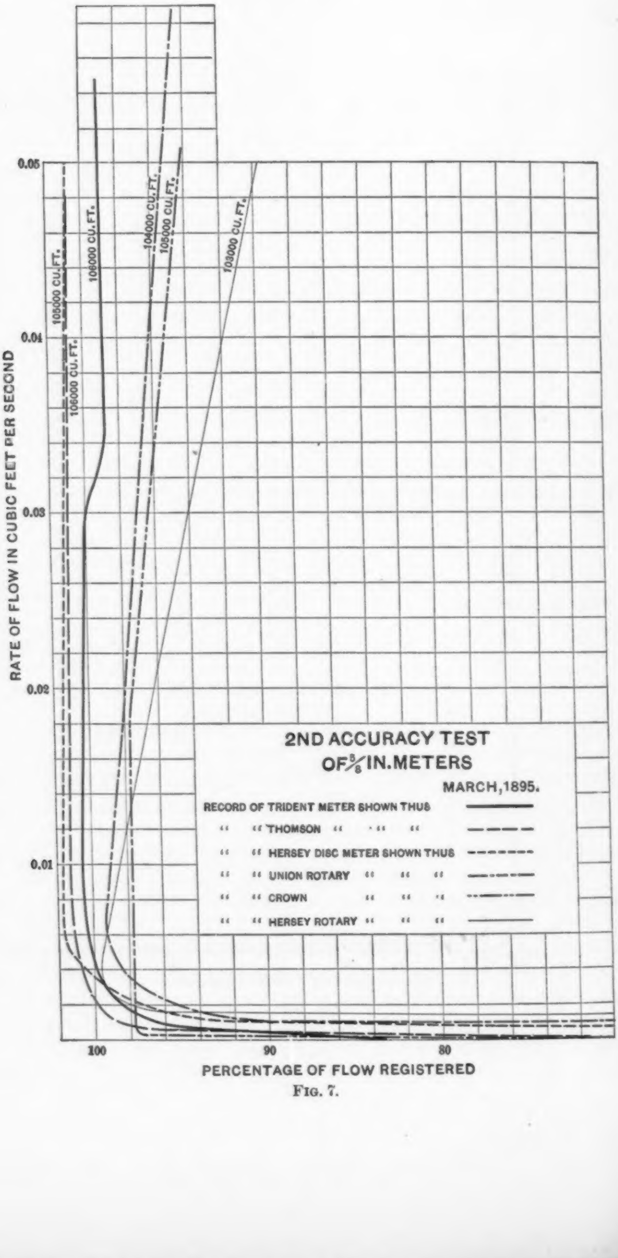


Fig. 7.

Mr. Smith.

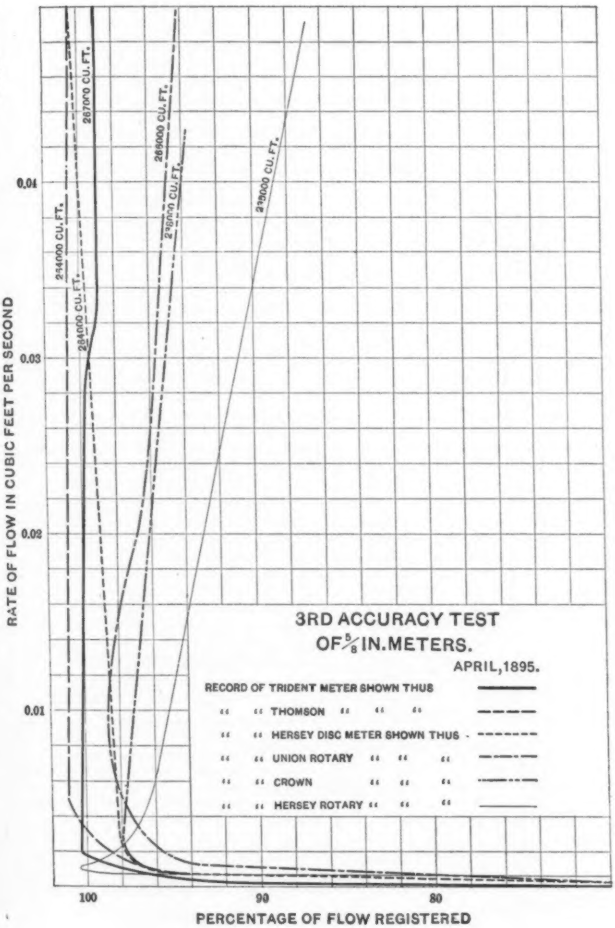


FIG. 8.

Mr. Smith.

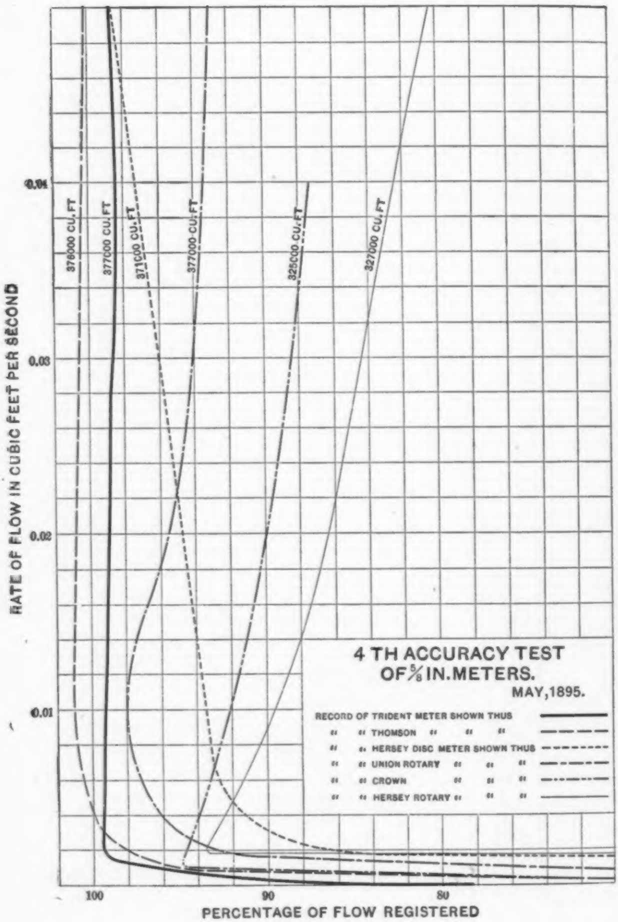


Fig. 9.

Mr. Smith.

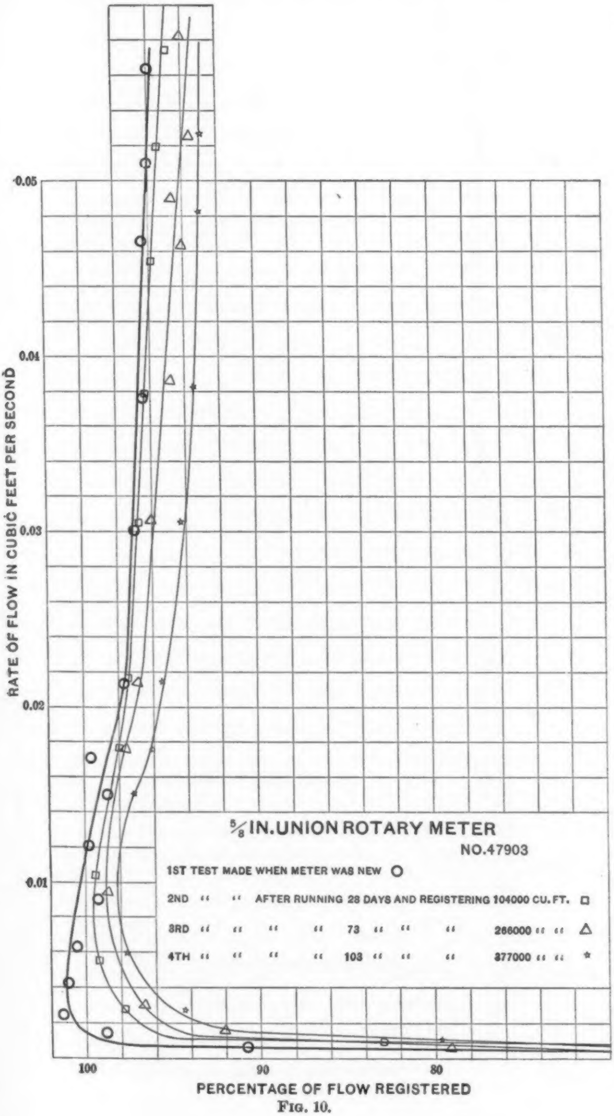


FIG. 10.

Mr. Smith.

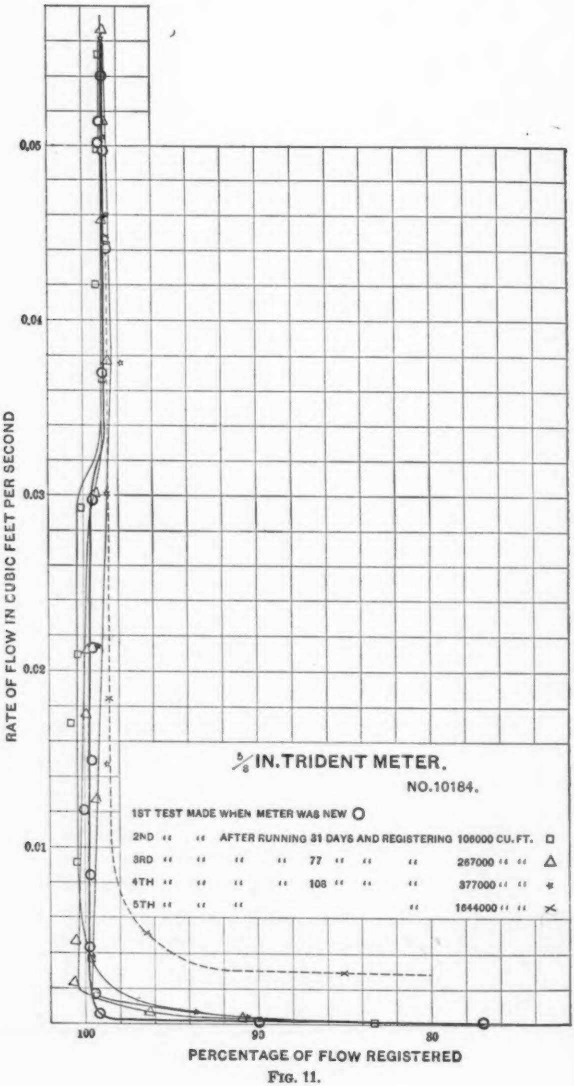


Fig. 11.

Mr. Smith.

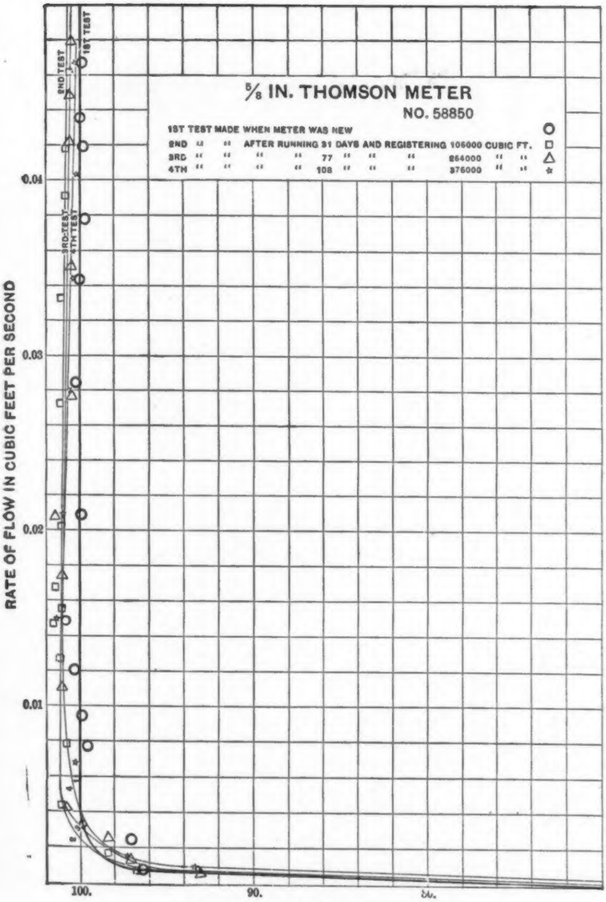


FIG. 12.

Mr. Smith.

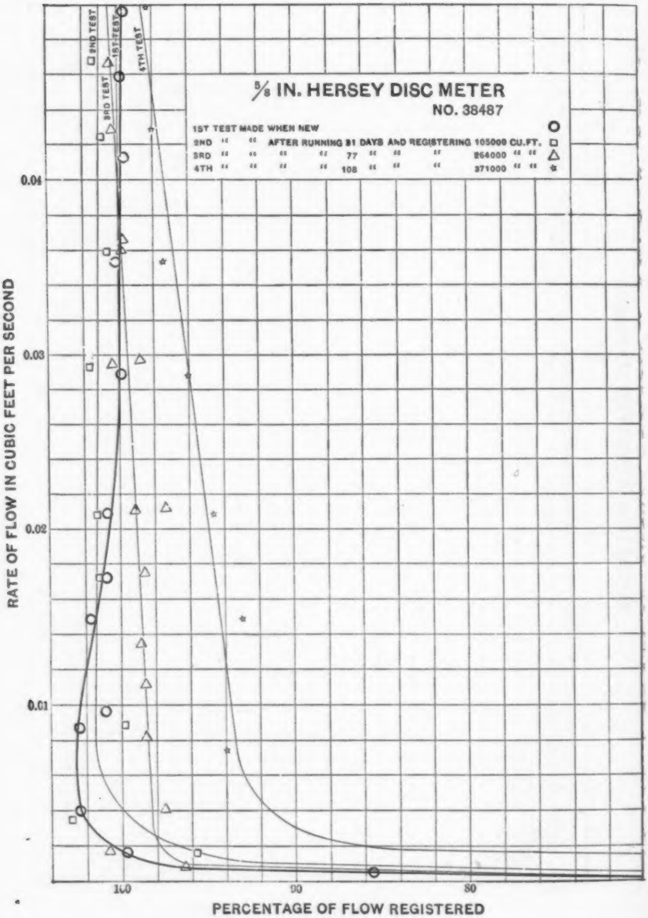


FIG. 13.

Mr. Smith.

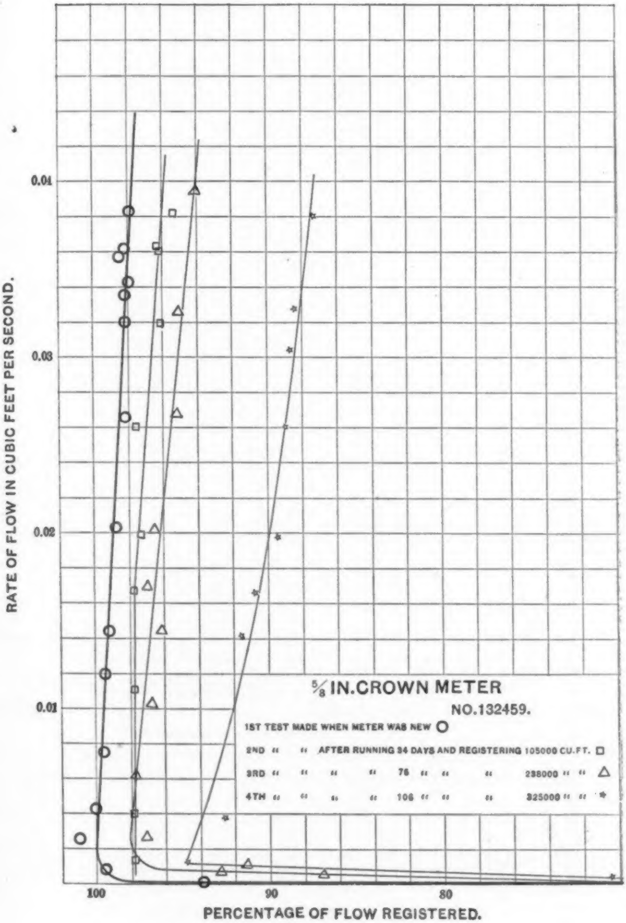


FIG. 14.

Mr. Smith.

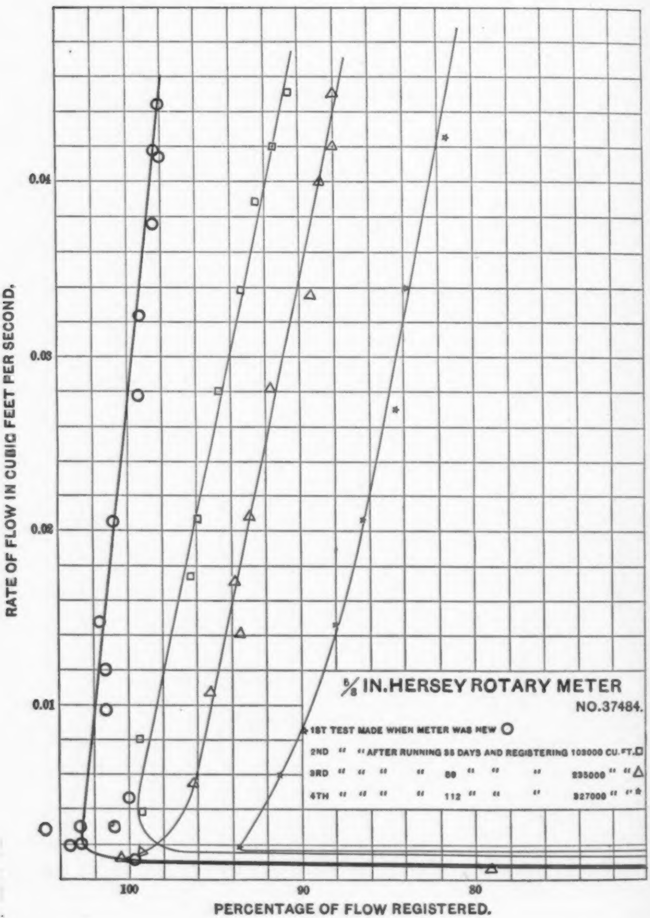


Fig. 15.

Mr. Smith

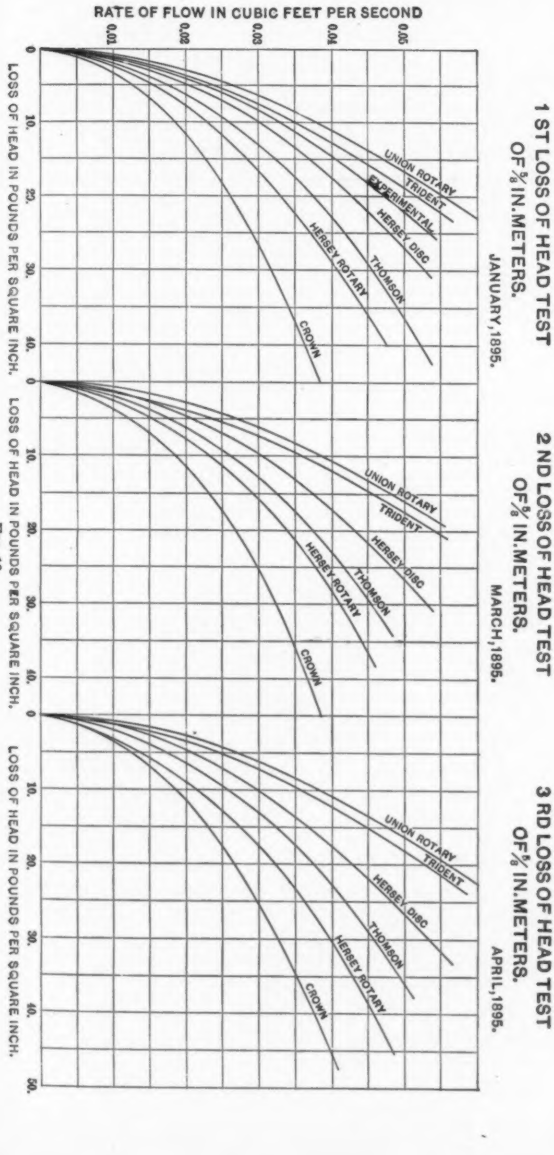


Fig. 16.

Mr. Smith. A few experiments were made to determine the effect of throttling the flow on the up-stream side of the meter, and the effect of suddenly starting and stopping the flow. These experiments indicated that neither condition materially affects the accuracy of any of the meters.

At the end of the first accuracy test, when the meters were new, the rate of flow at which the meters would just begin to register was determined. The results are shown in Table No. 23. The figures in the third and fourth columns are from the curves of the first accuracy test.

TABLE No. 23.

1 Name of Meter.	2 Least Flow Registered by Meter.		3 Rate at which Meter Registers 95% of Flow.		4 Rate at which Meter Registers 90% of Flow.	
	Cu. ft. per second.	Gallons per minute.	Cu. ft. per second.	Gallons per minute.	Cu. ft. per second.	Gallons per minute.
Union Rotary...	0.00026	0.117	0.00075	0.337	0.00068	0.306
Experimental....	0.00024	0.108	0.00115	0.517	0.00100	0.450
Trident..........	0.00003	0.013	0.00015	0.067	0.00010	0.045
Thomson.........	0.00004	0.018	0.00058	0.261	0.00045	0.202
Hersey Disc.....	0.00013	0.058	0.00062	0.279	0.00050	0.225
Crown...........	0.00003	0.013	0.00012	0.054	0.00012	0.054
Hersey Rotary..	0.00060	0.270	0.00090	0.405	0.00085	0.382

An inspection of the experimental curves, Figs. 10 to 15, will show that the effect of wear on the three disc meters is first to increase the percentage of registration, and afterward to decrease it, while the effect on the rotary type is gradually to decrease the percentage. It will also be observed that, with the disc meters, the vertical sweeps of the registration curves are very nearly parallel to the axis of abscissas, and the horizontal sweeps to the axis of ordinates.

The first indicates the susceptibility of the meter to accurate adjustment, and the second its sensitiveness. With the Rotary meter the vertical sweep is at quite an angle with the abscissa axis, indicating that it is possible to adjust the meter to register exactly right at but one point.

It will also be observed that the curves for the disc meters are much more permanent, and that the bulk of the evidence here presented favors this type of meter. Whether this holds good for meters of larger sizes cannot now be answered.

The loss-of-head curves (Fig. 16), show that continued wear has comparatively little effect on the loss of head, and it is practically the same in all these tests.

It is to be regretted that after laboring so hard, and spending so much time, but one meter each, of seven different types, has been investigated.

The experiments illustrate very clearly the general excellence of small meters of standard patterns, and also show very forcibly the fallacy of judging the merits of meters by their initial accuracy and sensitiveness. They also illustrate how exceedingly easy it is to be deceived. For example: One of the meters which showed almost perfect registration curves, and which had a long run before failing, is now being taken out of the market by the makers and replaced by one having its good points, with the bad ones eliminated. No one can make a series of tests such as are here recorded without being impressed with the wonderful accuracy of these little instruments, and the abuse they will stand without apparent injury. He will acquire a confidence in meter measurement which unfortunately for the waterworks superintendent is not shared by the average consumer. Mr. Smith.

These meters have been compared on the following points:

First.—Accuracy;

Second.—Sensitiveness;

Third.—Permanency;

Fourth.—Loss of head;

Fifth.—Capability of the meters to be adjusted for wear, and the cost of such adjustment;

Sixth.—Accessibility of the wearing parts of the meter;

Seventh.—Protection from injury from accidental freezing;

Eighth.—Cost.

Of all these, the most important is the permanency of the registration, both as regards accuracy and sensitiveness; in other words, the wearing qualities of the meter.

Instead of giving a table showing the comparison, and stating which meter is, in his opinion, the best, the speaker leaves the making of such comparison to those who are interested.

CLEMENS HERSCHEL, M. Am. Soc. C. E.—A report of tests of water meters, unless accompanied by diagrams showing the facts that have been disclosed by the experiments, is of doubtful value, and it is to be hoped that the author will supply diagrams to illustrate his experiments. The graphic representation of such experiments is much better than any set of tables can possibly be. All the speakers have delicately alluded to the fact that the results, as given in the paper, are either obscure or misleading, and it is hoped that the author will supply the diagrams, in order that this criticism may be made invalid and that they may be published with the paper. Mr. Herschel.

The experiments described and illustrated by Mr. Smith were made four years ago. At that time, or shortly after, the speaker wrote a paper in reference thereto, which was read before the New England Water-Works Association, on September 12th, 1895, and is published in the *Journal* of that Association.* The object of that paper was to argue

* *Journal* of the New England Water-Works Association, Vol. X, p. 109.

Mr. Herschel. for a public competitive test of all water meters then made. The names of the meters tested were not stated in the paper. They were referred to only by the numbers 1, 2, 3, 4, 5, 6 and 7, but their names may be given now. They are: (1) the Trident, (2) the Thomson, (3) the Hersey Disc, (4) the Union Rotary, (5) the Crown, (6) the Hersey Rotary, and (7) an experimental meter. A table in that paper gives their rank for accuracy, sensitiveness, permanency, loss of head, and price, after the first, second and third tests, as illustrated by Mr. Smith. With this explanation, the table will, of course, have more value than it had at that time. The following quotation is from the paper cited:

"They were tested for accuracy, and for loss of head caused by the meter, at various rates of discharge. Then about 100 000 cu. ft. were allowed to pass each meter, and the first set of tests were repeated. Then some 150 000 cu. ft. additional were allowed to pass each meter, and the first-named tests were again repeated. The quantity passed was equivalent to some ten years of ordinary use.

"Incidentally, therefore, these tests comprised a test for durability. Tests were also made for sensitiveness, and a test for remaining unaffected by continued disuse is still under way.

"The results were somewhat remarkable. They are given in the following table:

	First Test.							Second Test.							Third Test.						
	Rank.							Rank.							Rank.						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Accuracy..........	2	1	6	7	5	3	4	1	2	3	4	5	6	..	1	2	3	4	5	6	..
Sensitiveness......	1	5	2	3	4	7	6	1	5	2	3	4	6	..	s 1	a 2	m 5	e 3	6	4	..
Permanency.......	..	......	......	..	..	..	..	4	1	2	3	5	6	..	1	2	4	3	5	6	..
Loss of Head......	4	1	7	3	2	6	5	4	1	3	2	6	5	..	4	1	3	2	6	5	..
Price..............	1	sa 3	me 2	6	7	4	5	..	..	..	..	..	..	..	......	..	..	......	..	..	..

The speaker was loath to give the names at the time, having tested only seven meters, and it was his desire to instigate, if he could, a public test of all water meters then made in the United States, and in the market. He still has that desire, and thinks that nothing would tend to introduce water meters more generally, provoke their use, render their use more economical and cheapen the cost of repairs, which is a serious item in all water-works economy, than to have the kinds of meters on the market reduced in number. The water-meter business to-day and for years past has been in precisely the condition in which the turbine business was about fifteen years ago. At that time the number of American makes of water wheels and turbines was legion, and every one was claimed to be better than any other. There

were probably twenty-five or thirty makes of water wheels, but by means of public competitive tests more than three-fourths of them were at once shown to be out of date, and the results of the tests were known. The water-meter purchasing public is to-day entitled to the same class of information concerning water-meters. Let any one imagine the confusion there would be in the gas business if the number of makes of gas meters were as great as the present number of makes of water-meters. It is this kind of confusion that exists to-day among water superintendents in the use of water meters. Not every water-works superintendent can afford to spend either the time or the money requisite to test all these meters in a thorough manner. The diagrams given by Mr. Smith, showing the results of the tests made four years ago may seem to be simple, but the amount of labor involved in their preparation does not appear on the surface and yet they refer to tests of only seven meters. Mr. Herschel.

The arguments made by the speaker in the paper referred to, which was addressed to a society of water-works superintendents, was that, if an association of that sort was good for anything, it should work for the common good, and, instead of relegating the testing of water meters to individual members, should appoint a committee and, for the benefit of all the members, test all meters made. That is what is needed at the present day, and the speaker hopes that the opinion of this Society, either as a Society or by its individual members, on every occasion that presents itself, will be expressed in favor of the attainment of such an object. There is plenty of precedent for it, not only the precedent stated relating to the tests of turbine wheels, but take, as an example, the testing establishment operated by the Pennsylvania Railroad Company at Altoona, Pa., where there are some twenty or thirty skilled employees, and where purchases amounting to from $15 000 000 to $20 000 000 per annum depend on the tests made by that department. That is a case where tests are conducted by a single railroad company, but that company operates thousands of miles of railroad, and is itself constituted of many subordinate companies.

Another example is that of the New England Association of Railroad Superintendents, which is constantly testing new mechanisms for the benefit of all its members, and there are other similar cases. It is economy of labor to operate in that manner, and if what the speaker has said shall tend to bring the procuring of such tests of water-meters one step nearer, he will feel amply repaid.

CORRESPONDENCE.

Mr. Harlow.

JAMES H. HARLOW, M. Am. Soc. C. E.—An examination of this paper confirms the writer in the position taken by him at the American Water Works Convention, at Buffalo, in May, 1898. Table No. 1 shows that when the orifice of discharge is small, the accuracy of the meter is materially changed. Omitting from Table No. 1 the best and poorest meters, the error of registering, at $\frac{1}{32}$-in. opening, is from 10 to 32 per cent. At Buffalo the writer took the ground that in the ordinary use of water the user opens the faucet so that the discharge approximates the nominal capacity of the meter, and in such case the error is small; but it is the detection of comparatively small streams that is desirable.

From five years' records in Wilkinsburg, Pa., it is found that the average domestic consumer uses 7 500 cu. ft. of water per annum. This, at the meter rates of Wilkinsburg, would amount to $11.28. Assuming it possible that there may be an error of 10%, and that the error is in favor of the consumer, the amount actually used would be 8 300 cu. ft. This would amount to $12.40; the loss to the Water Company being $1.12. A casual examination of 3 500 meter tests shows that the errors of meters, at one-half and full capacity, about balance each other, and therefore there is no real loss. On the other hand, it is found that meters, as a rule, will allow small leaks to pass without registering, and it is for this reason that all meters used by the writer are given what is called a "time test."

This test is based on the fact that, with practically uniform pressure, the orifice of discharge is smaller when the time to pass a given quantity of water is greater. The writer's rule is: To accept no meter which passes $\frac{1}{10}$ cu. ft. of water in less than 90 seconds. In this test the valve is opened slowly and to just the amount necessary to set the meter registering, the pressure being about 130 lbs. per square inch. Under this pressure, assuming $v = 60 \sqrt{2 g h}$, there will be required an orifice of about 0.000044 sq. ft., which corresponds to a circular opening of a little less than $\frac{3}{32}$ in. in diameter.

Remembering that in this test the valve is opened just enough to start the meter registering, and that a less opening would allow water to pass, and, not registering, there may be a constant leak of something less than $\frac{1}{10}$ cu. ft. in 90 seconds, which is not recorded.

Assuming that 0.05 cu. ft. of water per 90 seconds does not start the meter, there is a possible leak of 17 500 cu. ft. per year, which amounts to more than twice the amount of water registered against the average customer, even after adding 10% for the assumed error.

The writer would like to ask if any members of the Society have records which show the relative amount registered by their consumer's meters, as compared with the total amount of water pumped. From observations made by the writer's company he is satisfied that not more than 75% of the water actually used by metered customers is measured; and he believes that in order to approximate the amount of water used there must be sought a smaller meter, or one that will register the small streams. Mr. Harlow.

Since the writer began to make systematic tests of meters he has obtained an average time test of 134 seconds, as against 90 seconds obtained five years ago, and for a meter of the same make. The 90 seconds' time test gives 35 000 cu. ft. per year as a possible loss through a meter. The 134 seconds' time test, under the same conditions, gives 23 500 cu. ft., a possible gain of 12 500 cu. ft. per year, which is registered and paid for, or the leak is stopped.

The best meter now being used by the writer's company gives an average time test of 234 seconds, or at the rate of 13 500 cu. ft. of water per year.

In June, 1898, four of the best piston meters were placed tandem on the service line furnishing water to the building in which the Water Company has its office. These meters were tested at the time they were placed on the service line, and have been again tested to-day.

From Saturday afternoon, June 4th, until Monday morning, June 6th, 1898, for 38 hours 30 minutes these four meters were tested by allowing as small a stream of water to pass as would just move the register of the slowest meter. At the end of this time, meter No. 1 read 58 cu. ft.; No. 2, 17 cu. ft.; No. 3, 19 cu. ft.; and No. 4, 42 cu. ft. Assuming the efficiency of meter No. 1 to be equal to unity, then No. 2 will equal 0.293; No. 3, 0.344, and No. 4, 0.724. The total amount of water passing these four meters in eight months was: No. 1, 26 065 cu. ft.; No. 2, 17 738 cu. ft.; No. 3, 20 043 cu. ft., and No. 4, 25 407 cu. ft. Assuming No. 1 to be correct, their ratios of efficiency will be: No. 2, 0.671; No. 3, 0.768, and No. 4, 0.985.

Comparing the above figures with the tests given in Table No. 24, it will be seen that when the meters were placed on the service line the error in one-half and full stream was within $\frac{7}{10}$ of 1%, which is the record of meter No. 3.

It will also be noted that, with the exception of meter No. 2, all these meters, under the test made to-day, register from 1 to 5% slow.

The meter tested under the longest time test shows the largest amount of water passing during the eight months. The difference as shown is due to small leaks which meters Nos. 1 and 2 did not succeed in registering.

Mr. Harlow. The writer will be pleased if someone else takes up this question of a meter that will catch the small streams.

TABLE No. 24.

METER.	No. 1.		No. 2.		No. 3.		No. 4.	
Date of test.	June, 1898.	Jan., 1899.	June, 1898.	Jan., 1899.	June, 1898.	Jan., 1899.	June, 1898.	Jan., 1899.
	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
Time test.	1 121	228	150	226	119	107	261	222
Half open.	O. K.	1% slow.	O. K.	O. K.	0.7% slow.	1.3% slow.	O. K.	4% slow.
Full open.	O. K.	1.3% "	O. K.	O. K.	0.7% "	1.7% "	O. K.	5% "

Mr. Hawley. W. C. HAWLEY, Assoc. M. Am. Soc. C. E.—A careful investigation of the subject has led the writer to the same conclusion as that reached by the author regarding the relative merits of the rotary and disc types of water meters. The disc meter, for a given size, costs less, and while, when new, there is little difference in accuracy and sensitiveness between the two types, after having registered 100 000 cu. ft., or more, the advantage as a rule is decidedly with the disc meters.

Another point in favor of the disc meters is that sand or other foreign matter is less likely to stop them than it is to stop the rotary meters. This is especially true in the smaller sizes, and where the water pressure is not high. This is an important matter, for rotary meters of the Crown and Hersey types will usually, when stopped, pass from 60 to 75% of the full flow when running, and hence the stoppage does not attract attention, and frequently the loss in registration amounts to more than the cost of the meter.

Illustrating the surprising accuracy of new disc meters mentioned by the author, the Water Department of which the writer is Superintendent recently purchased 1 000 disc meters. The specifications for $\frac{5}{8}$-in. and $\frac{3}{4}$-in. meters required that the average of the tests on the larger streams, down to and including the tests on the $\frac{1}{8}$-in. stream, should be within the limits of 625 and 630 lbs. on a registration of 10 cu. ft., and that no single test should exceed the limits of + 1% and — 2% (618 $\frac{3}{4}$ lbs. and 637 $\frac{1}{2}$ lbs.). The $\frac{1}{16}$-in. and $\frac{1}{32}$-in. tests should be within the limits of + 1% and — 5% (61$\frac{9}{16}$ lbs. and 65$\frac{5}{8}$ lbs.) on a registration of 1 cu. ft. The tests for 1-in. meters were the same, except that no test on a $\frac{1}{32}$-in. stream was required. Of the first 250 meters delivered, about sixty failed to register within the limits, though previously tested satisfactorily at the factory. On investigation it was found that water at a temperature of about 50° Fahrenheit had been used for testing at the factory, while the water

used in testing for the Water Department, had a temperature of about 70 degrees. So closely does the disc fit the disc chamber, that this slight difference in temperature affected the registration. A little scraping of the discs brought all the rejected meters within the requirements. Of the balance of the order, 750, not one failed to test satisfactorily. Mr. Hawley.

The author considers the essentials of a good water meter to be, as quoted from Mr. Iben:

(1) Sensitiveness or accuracy of registry at different rates of discharge;

(2) Capacity for a given size of meters;

(3) Cost;

(4) Durability.

The writer would suggest the propriety of placing accuracy and sensitiveness under separate heads. A meter may be very accurate on high rates of discharge and fail absolutely to register a small rate; or it may be sensitive to both large and small rates and accurate on but part or none of them. It is desirable that a meter should be sensitive to any flow, and as accurate within proper limits as good substantial construction and reasonable cost will allow. A meter made so sensitive that it will register on the extremely small rates of discharge will probably be too delicate to stand the severe strain of measuring at high rates of discharge. Just what degree of sensitiveness should be required on small rates of discharge must be determined by the conditions under which the meter works, the pressure, amount of silt and sand in the water, etc. For the $\frac{5}{8}$-in. and $\frac{3}{4}$-in. sizes a rate of 1 cu. ft. per hour should be the limit required for new meters under ordinary conditions, though they will frequently do even better.

To the essentials for a good water meter which are mentioned by the author, the writer would add:

(*a*) Accessibility of working parts, and ease and speed with which they can be reassembled;

(*b*) A minimum of cost of repairs, in case of damage caused by freezing;

(*c*) A minimum of liability to stoppage from sand or other foreign substance.

These relate directly to the cost of maintenance, and, in the course of the life of a meter, are important items.

In asking for proposals for furnishing meters in August, 1897, the writer specified that each bidder should submit with his proposal the following guarantees:

"A definite guarantee must be given by each bidder for each size of meter, specifying the maximum cost of repairing meters which have been damaged by freezing. Said guarantee to cover the cost of new parts to replace those damaged by frost, and also the time of man in making the repairs; and this guarantee shall remain in force

Mr. Hawley. so long as the meters purchased under these specifications are in service.

"A similar guarantee must be given specifying the maximum cost of repairing meters of the various sizes in case of damage by hot water.

"A similar guarantee must be given specifying for each size of meter the cost of such principal parts as may be required for renewing worn parts or for repairing meters accidentally damaged."

In the above guarantees "the time of man in making repairs" was included because of the inaccessibility of the working parts of some meters, and the consequent loss of time in making repairs as compared with others. The representative of each meter company bidding was ready, in conversation, with sundry proofs and reasons why his particular meter was the most economical to maintain; but when called upon to state this in actual figures with a bond behind them, only one of four complied. The advisability of exacting these guarantees, particularly that relating to damage by freezing, has been fully demonstrated during the cold weather of the present winter.

A year ago the writer made tests of some meters that had been in service for about twenty months, and had passed large quantities of water. Table No. 25 shows both the original test and the second test, and compares the two. The percentages of registration given are the ratios of the meter registration to the tank measurement in each case, *i. e.*,

$$100\left(\frac{\text{meter registration}}{\text{tank measurement}}\right).$$

The writer prefers this to the author's method, as the ratio is based upon exact measurement, and not upon the constantly varying registration of the meter. Hence it gives at once just the percentage of water actually passed by the meter and registered, and avoids the necessity of using the + and — signs. These tests were made under a pressure of 38 to 43 lbs., the water being brought to the testing table in a 4-in. pipe from a point on the force main close to the stand pipe. The pressure was therefore very uniform. Its temperature, though not taken, was known to vary but slightly.

After testing, the meters were taken apart and examined carefully, and their condition noted.*

These and other tests and examinations lead the writer to believe that while most of the standard makes of disc meters are reliable for ordinary service when new, there is a decided difference in their durability, and hence some of them are much less sensitive than others after having been in service for a time.

The principal reason for this is the friction between the disc and the vertical diaphragm which divides the disc chamber. In several styles of disc meters the tendency of the disc to rotate about a line coinciding

* See the column headed Remarks.

with the center of its spindle, is overcome by direct contact between the edge of the disc and the diaphragm. This constant rubbing, aided by what little grit there may be in the water, in course of a few million oscillations of the disc causes wear, both on the diaphragm, and on the edge of the disc in contact with it, and a consequent increase in friction to such an extent that the meter loses, to a greater or less degree, its sensitiveness to small flows. This is frequently so serious a matter that nothing smaller than a $\frac{1}{8}$-in. stream will be registered. This means that in case of a small leak, from 500 to over 4 000 galls. per 24 hours would pass without registering. One or two manufacturers have overcome this difficulty by introducing a roller which is attached to the edge of the disc and which works either in a slot cut into the inner surface of the disc chamber, or directly against the diaphragm itself. This prevents the sliding contact between disc and diaphragm and the consequent wear. Mr. Hawley.

Incidentally, the writer would call attention to the fact that the lack of sensitiveness, after having been in service for a time, is more marked in rotary than in disc meters, and doubtless accounts to a large extent for the considerable difference between total pumpage and total meter registration, which has been noticed in cities where such records have been kept, and which has been mentioned in papers and discussions before this Society.

The intermediate gear train which transfers and reduces the motion from the disc spindle to the dial clockwork is one of the delicate parts of a meter, and wear here soon affects the sensitiveness of the meter. The use of a differential gear for this purpose has proven very unsatisfactory. Some of the forms of single-train gears are little better, though there are some excellent ones in the market. One of the best gear trains made, both as regards a minimum of friction and wearing qualities, is the compound train in the Trident meter, which was designed by John Thomson, M. Am. Soc. C. E.

One bad form of construction, sometimes used, is to fasten a gear to a shaft with a set-screw. With the continual jar due to the operation of the meter the set-screw is very liable to work loose or slip on the shaft and hence the meter fails to register.

The writer doubts the practicability of a manufacturer's diagram to indicate the proper correction for registration as time passes, which is based upon the quantity registered only. Time is an important element in the wear of a meter. A given quantity of water measured at a high rate of discharge will cause much more wear than the same quantity measured at a low rate. An actual test is probably the only safe method of determining the matter.

Mr. Hawley.

TABLE No. 25—(*Continued*).—HERSEY DISC METERS TESTED IN FEBRUARY, 1898.

⅝..	47 208	¾	625	641½	20	151 000	625	666½	97.4	93.8	− 3.6	Good condition.
	....	¼	62½	63	....	....	62½	66	99.2	94.7	− 4.5	
	....	⅛	62½	63	....	....	62½	67	99.2	93.3	− 5.9	
	....	1/16	31¼	32	....	....	Would not	register.	97.7	0.0	−97.7	
⅝..	46 065	¾	625	631	22	146 000	625	628½	99.0	99.4	+ 0.4	Good condition.
	....	¼	62½	61	....	....	62½	62	102.4	100.8	− 1.6	
	....	⅛	62½	62½	....	....	62½	63¼	100.0	98.8	− 1.2	
	....	1/16	31¼	33	....	....	31¼	37	94.7	84.5	−10.2	
	....	1/32	Not	tested.	....	....	Regis	tered.	....	....	....	
⅝..	46 063	¾	625	635	22	112 000	625	636½	98.4	98.2	− 0.2	Good condition except guide frame for spindle.
	....	¼	62½	61½	....	....	62½	62½	101.6	100.0	− 1.6	
	....	⅛	62½	61¼	....	....	62½	63	101.6	99.2	− 2.4	
	....	1/16	31¼	31¾	....	....	31¼	34	99.2	91.9	− 7.3	
	....	1/32	Not	tested.	....	....	Regis	tered.	....	....	....	
⅝..	46 120	¾	625	632	22	177 000	625	688½	98.9	90.8	− 8.1	Diaphragm somewhat worn, also disc chamber. On 1/16-in. stream meter ran 3½ tenths of cu. ft. and stopped. Would not register again on 1/16-in. stream.
	....	¼	62½	63	....	....	62½	74	99.2	84.5	−14.7	
	....	⅛	62½	61	....	....	62½	71½	102.4	87.4	−15.0	
	....	1/16	31¼	32½	....	....	21$\frac{9}{10}$	40	96.2	54.8	−41.4	
	....	1/32	Not	tested.	....	....	Would not	register.	....	....	....	
¾..	46 055	¾	625	633	23	125 300	625	656½	98.7	95.2	− 3.5	Disc chamber worn bright on one side. Diaphragm considerably worn. Clips for holding guide frame for spindle were worn off. Frame loose.
	....	¼	62½	62¾	....	....	62½	66½	99.6	94.0	− 5.6	
	....	⅛	62½	61¼	....	....	62½	67	102.0	93.3	− 8.7	
	....	1/16	31¼	31½	....	....	Would not	register.	99.2	0.0	−99.2	
	....	1/32	6¼	....	....	....	....	....	....	....	....	
¾..	46 047	¾	625	626½	23	137 500	625	655	99.8	95.4	− 4.4	Diaphragm slightly worn, also disc chamber. Clips for holding guide frame for spindle in place were worn off. Frame loose.
	....	¼	62½	61¾	....	....	62½	65	101.2	96.2	− 5.0	
	....	⅛	62½	62	....	....	62½	65	100.8	96.2	− 4.6	
	....	1/16	31¼	32	....	....	31¼	36½	97.7	85.3	−12.4	
	....	1/32	6¼	6¼	....	....	Regis	tered.	100.0	?	....	
1..	46 032	1	Not	tested.	23	100 529	625	637	....	98.1	....	
	....	¾	625	634	....	....	625	636½	98.5	98.2	− 0.3	Disc spindle worn on one side. Guide for spindle showed a little wear.
	....	½	Not	tested.	....	....	625	635	....	98.4	....	
	....	¼	62½	62¼	....	....	62½	62½	100.4	100.0	− 0.4	
	....	⅛	62½	62½	....	....	62½	63	100.0	99.2	− 0.8	
	....	1/16	31¼	33⅞	....	....	31¼	35	93.3	89.3	− 4.0	
	....	1/32	6¼	6¾	....	....	Regis	tered.	92.6	?	....	

Mr. Hawley.

TABLE No. 25.—BEE METERS TESTED IN FEBRUARY, 1898.

Size. Inches.	No. of meter.	Size of stream. Inches.	Original Test.		Time in service. Months.	Total registration. Cubic feet.	Second Test.		Registration.			Remarks.
			Meter. Pounds.	Scales. Pounds.			Meter. Pounds.	Scales. Pounds.	Original test. Percentage.	Second test. Percentage.	Change in registration. Percentage.	
⅝..	75 100	¾	625	630	20	119 000	625	630	99.2	99.2	0.0	Meter in good condition, except diaphragm and disc, which were both somewhat worn. Differential gear (intermediate) not examined.
	....	¼	62½	62½	....	....	62½	63	100.0	99.2	— 0.8	
	....	⅛	62½	63½	....	....	62½	65	98.4	96.2	— 2.2	
	....	$\frac{1}{16}$	31¼	32½	....	....	31¼	39	96.2	80.1	— 16.1	
	....	$\frac{1}{32}$	Not	tested.	....	....	Meter	regist'd.	....	?	....	
⅝..	73 581	¾	625	629	23	233 000	625	665½	99.4	94.0	— 5.4	Differential gear badly worn. Diaphragm and disc considerably worn. Disc chamber slightly worn.
	....	¼	62½	63	....	....	62½	66¾	99.2	94.3	— 4.9	
	....	⅛	62½	63½	....	....	62½	69½	98.4	90.0	— 8.4	
	....	$\frac{1}{16}$	31¼	33	....	....	Did not	register.	94.7	0.0	— 94.7	
	....	$\frac{1}{32}$	6¼	6¼	....	....	....	....	100.0	0.0	—100.0	
⅝..	75 080	¾	625	625½	21	98 900	625	637	99.9	98.1	— 1.8	Differential gear somewhat worn, also diaphragm.
	....	¼	62½	61	....	....	62½	62½	102.4	100.0	— 2.4	
	....	⅛	62½	63½	....	....	62½	64	98.4	97.7	— 0.7	
	....	$\frac{1}{16}$	31¼	33½	....	....	Did not	register.	93.3	0.0	— 93.3	
¾..	73 668	¾	625	633	23	457 800	625	649½	98.7	96.2	— 2.5	Differential gear badly worn. Diaphragm considerably worn.
	....	¼	62½	62½	....	....	62½	66	100.0	94.7	— 5.3	
	....	⅛	62½	64	....	....	62½	68	97.7	91.9	— 5.8	
	....	$\frac{1}{16}$	31¼	32¾	....	....	Did not	register.	95.4	0.0	— 95.4	
	....	$\frac{1}{32}$	6¼	7½	....	....	....	....	83.3	0.0	— 83.3	
¾..	81 914	¾	625	623	19	110 000	625	628	100.3	99.5	— 0.8	Differential gear somewhat worn, also diaphragm.
	....	¼	62½	60½	....	....	62½	63	103.3	99.2	— 4.1	
	....	⅛	62½	62½	....	....	62½	64½	100.0	96.9	— 3.1	
	....	$\frac{1}{16}$	31¼	33	....	....	31¼	37½	94.7	83.3	— 11.4	
	....	$\frac{1}{32}$	Not	tested.	....	....	Regis	tered.	....	?	....	
	....	1	"	"	....	....	625	668	....	93.6	....	
1..	73 683	¾	625	632	23	537 270	625	671	98.9	93.1	— 5.8	Disc chamber worn bright. Diaphragm somewhat worn. No record made of condition of differential gear.
	....	¼	625	626½	....	....	625	667	99.9	93.7	— 6.2	
	....	⅛	62½	62½	....	....	62½	79	100.0	79.1	— 20.9	
	....	$\frac{1}{16}$	62½	65	....	....	Did not	register.	96.2	0.0	— 96.2	
	....	$\frac{1}{32}$	31¼	32½	....	....	"	"	96.2	0.0	— 96.2	

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TABLE No. 25—(*Continued*).—NASH METERS TESTED IN FEBRUARY, 1898.

5/8..	158 826	3/4	625	628½	23	160 000	625	670	99.4	93.3	— 6.1	Spindle worn. Diaphragm and disc chamber slightly worn, otherwise in good condition.
	....	1/4	62½	62½	....	....	62½	67	100.0	93.3	— 6.7	
	....	1/8	62½	62½	....	....	62½	67	100.0	93.3	— 6.7	
	....	1/16	31¼	31½	....	....	31¼	37¼	98.4	83.9	- 14.5	
	....	1/32	6¼	6¼	....	....	Registered.		100.0	?	....	
5/8..	158 795	3/4	625	626½	24	117 700	625	662	99.8	94.4	— 4.4	Spindle badly worn. Diaphragm worn, otherwise in good condition.
	....	1/4	62½	62½	....	....	62½	66½	100.0	94.0	— 6.0	
	....	1/8	62½	62½	....	....	62½	66	100.4	94.7	— 5.7	
	....	1/16	31¼	31½	....	....	31¼	36	99.2	86.8	— 12.4	
	....	1/32	6¼	6¼	....	....	Would not register.		100.0	0.0	....	
5/8..	158 820	3/4	625	628¼	24	108 600	625	661	99.4	94.6	— 4.8	Spindle badly worn. Diaphragm slightly worn, otherwise in good condition.
	....	1/4	62½	62½	....	....	62½	66	100.0	94.7	— 5.3	
	....	1/8	62½	62	....	....	62½	68	100.8	91.9	— 8.9	
	....	1/16	31¼	31	....	....	Would not register.		100.8	0.0	—100.8	
	....	1/32	6¼	6¼	....	....	"	"	100.0	....	....	
3/4..	160 538	3/4	625	622	22	124 400	625	620	100.5	100.8	+ 0.3	Spindle nearly worn off and driving arm badly worn.
	....	1/2	No test.		....	....	62½	62½	....	100.0	....	
	....	1/4	62½	64½	....	....	62½	61½	96.9	101.6	+ 4.7	Diaphragm slightly worn, otherwise in good condition.
	....	1/8	62½	61½	....	....	62½	61¾	101.6	101.2	— 0.4	
	....	1/16	31¼	31½	....	....	62½	62½	99.2	100.0	+ 0.8	
	....	1/32	No test.		....	....	Registered.		....	....	....	
3/4..	158 732	3/4	625	625	24	178 600	625	642½	100.0	97.3	— 2.7	Disc chamber somewhat worn. Spindle slightly worn. Diaphragm considerably worn.
	....	1/4	62½	60¾	....	....	62½	63	102.9	99.2	— 3.7	
	....	1/8	62½	59	....	....	62½	62½	106.0	100.0	— 6.0	
	....	1/16	31¼	29½	....	....	Would not register.		106.0	0.0	—106.0	
	....	1/32	6¼	6½	....	....	"	"	96.2	....	....	
3/4..	160 544	3/4	625	630¾	22	235 100	625	660	99.1	94.7	— 4.4	Meter found stuck and disc warped out of shape, probably by hot water. Put in new disc and tested, with results shown. Spindle of old disc badly worn, also diaphragm. Spindle considerably worn. Diaphragm slightly worn. Otherwise meter in good condition.
	....	1/4	62½	61½	....	....	62½	65	101.6	96.2	— 5.4	
	....	1/8	62½	60	....	....	62½	64½	104.2	96.9	— 7.3	
	....	1/16	31¼	31¾	....	....	Would not register.		98.4	0.0	— 98.4	
3/4..	160 531	3/4	625	624¾	22	235 600	625	644	100.1	97.0	— 3.1	
	....	1/4	62½	59½	....	....	62½	65	105.0	96.2	— 8.8	
	....	1/8	62½	63½	....	....	62½	63	98.4	99.2	+ 0.8	
	....	1/16	31¼	31¾	....	....	62½	65	98.4	96.2	— 2.2	
	....	1/32	No test.		....	....	Would not register.		....	....	....	
1..	158 888	1	625	632½	20	705 380	625	660	98.8	94.7	— 4.1	Disc and spindle worn. Disc chamber worn. Rest of meter in good condition.
	....	3/4	625	624½	....	....	625	665	100.1	94.0	— 6.1	
	....	1/4	62½	65	....	....	62½	78	96.2	80.0	— 16.2	
	....	1/8	62½	58½	....	....	62½	67	106.8	93.3	— 13.5	
	....	1/16	31¼	32	....	....	62½	78	97.7	80.0	— 17.7	
	....	1/32	No test.		....	....	Registered.		....	....	....	

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TABLE No. 25—(*Continued*).—Niagara Meters Tested in February, 1898.

Size. Inches.	No. of meter.	Size of stream. Inches.	Original Test.		Time in service. Months.	Total registration. Cubic feet.	Second Test.		Registration.			Remarks.
			Meter. Pounds	Scales. Pounds			Meter. Pounds.	Scales. Pounds.	Original test. Percentage.	Second test. Percentage.	Change in registration. Percentage.	
⅝..	5 355	¾	625	629½	23	88 800	625	639	99.2	97.8	—1.4	Intermediate gear considerably worn. Diaphragm slightly worn. Disc good.
....	....	¼	62½	61¾	....	....	62½	63½	101.2	98.4	—2.8	
....	....	⅛	62½	61¾	....	....	62½	64	101.2	97.7	—3.5	
....	....	1/16	31¼	31	....	....	31¼	36½	100.8	85.6	—15.2	
....	....	1/32	Not tested.		....	....	Registered.		?	0.0	....	
⅝..	5 308	¾	625	631	23	147 800	625	648	99.0	96.5	—2.5	Intermediate gear somewhat worn. Spindle worn. Diaphragm very slightly worn.
....	....	¼	62½	61	....	....	62½	64½	102.4	96.9	—5.5	
....	....	⅛	62½	61	....	....	62½	65	102.4	96.2	—6.2	
....	....	1/16	31¼	31¼	....	....	31¼	37½	100.0	83.3	—16.7	
....	....	1/32	Not tested.		....	....	Did not register.		?	0.0	....	
⅝..	5 396	¾	625	630½	22	69 500	625	640	99.1	97.7	—1.4	Diaphragm very slightly worn. Otherwise meter in good condition.
....	....	¼	62½	62	....	....	62½	63	100.8	99.2	—1.6	
....	....	⅛	62½	61¼	....	....	62½	64½	102.0	96.9	—5.1	
....	....	1/16	31¼	32½	....	....	Did not register.		96.2	0.0	—96.2	
¾..	5 951	¾	625	629	21	138 100	625	622½	99.4	100.4	+1.0	Diaphragm badly worn, also edges of disc. Otherwise in good condition.
....	....	¼	62½	61¾	....	....	62½	61¾	101.2	101.2	0.0	
....	....	⅛	62½	61	....	....	62½	62½	102.4	100.0	—2.4	
....	....	1/16	31¼	29½	....	....	Did not register.		105.9	0.0	—105.9	
¾..	6 024	¾	625	624	20	216 100	625	614	100.1	101.8	+1.7	
....	....	¼	62½	60	....	....	62½	61	104.2	102.4	—1.8	Spindle somewhat worn, otherwise in good condition.
....	....	⅛	62½	59½	....	....	62½	60½	105.0	103.3	—1.7	
....	....	1/16	31¼	30½	....	....	31¼	33¾	102.4	92.6	—9.8	
....	....	1/32	Not tested.		....	....	Registered.		?	?	....	
¾..	5 973	¾	625	630	21½	172 300	625	610	99.2	102.4	+3.2	Diaphragm slightly worn, otherwise in good condition.
....	....	¼	62½	62½	....	....	62½	61	100.0	102.4	+2.4	
....	....	⅛	62½	60	....	....	62½	61½	104.2	101.6	—2.6	
....	....	1/16	31¼	30¾	....	....	31¼	32½	101.6	96.2	—5.4	
....	....	1/32	Not tested.		....	....	Did not register.		?	0.0	....	
¾..	5 950	¾	625	625½	21	235 200	625	625	99.9	100.0	+0.1	
....	....	¼	62½	62½	....	....	62½	62	100.0	100.8	+0.8	Meter in fine condition. Wear on disc chamber perfectly even. The whole interior surface of disc chamber polished bright.
....	....	⅛	62½	62½	....	....	62½	63	100.0	99.2	—0.8	
....	....	1/16	31¼	31¼	....	....	31¼	33	99.2	94.7	—4.5	
....	....	1/32	Not tested.		....	....	Meter registered.		?	?	....	

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TABLE No. 25.—TRIDENT METERS TESTED IN FEBRUARY, 1898.—(*Continued.*)

¾..	17 397	¾	62½	61½	22	168 600	625	615½	101.6	101.5	− 0.1	Meter in good condition. No wear apparent.
	....	¼	62½	61	....	....	62½	61	102.4	102.4	0.0	
	....	⅛	62½	60½	....	....	62½	60¼	103.3	103.7	+ 0.4	
	....	1/16	31¼	31	....	....	31¼	31¼	100.8	100.0	− 0.8	
	....	1/32	6¼	7	....	....	6¼	6¼	89.3	100.0	+10.7	
¾..	17 387	¾	62½	63	22	149 500	625	638½	99.2	97.9	− 1.3	Meter in good condition. No wear apparent.
	....	¼	62½	62 ½	....	....	62½	63½	100.0	98.4	− 1.6	
	....	⅛	62½	62½	....	....	62½	63½	100.0	98.4	− 1.6	
	....	1/16	62½	65	....	....	31¼	38	96.2	82.2	−14.0	
	....	1/32	Regis	tered.	....	....	Regis	tered.	?	?	....	
¾..	17 393	¾	625	635	22	149 200	625	622¼	98.4	100.4	+ 2.0	Meter in good condition. No wear apparent, except that change gear had slipped off of driving shaft from intermediate gear, and end of shaft was slightly worn. Change gear replaced and meter tested, with results shown.
	....	¼	62½	62	....	....	62½	62¼	100.8	100.4	− 0.4	
	....	⅛	62½	62½	....	....	62½	62½	100.0	100.0	0.0	
	....	1/16	31¼	32½	....	....	31¼	35½	96.2	88.0	− 8.2	
	....	1/32	Not	tested.	....	....	Regis	tered.	....	?	....	
¾..	17 390	¾	625	629	22	202 000	62½	64¼	99.4	97.3	− 2.1	This meter had been working entirely immersed in muddy water most of time since first set. First test on ¾-in. stream gave 750 lbs. for 10 cu. ft. registration. Examination showed that grit had entered stuffing box of driving shaft from intermediate gear, causing it to turn very hard, and the intermediate gear was worn out. Replaced with new one and tested, as shown.
	....	¼	62½	62½	....	....	62½	63½	100.0	98.4	− 1.6	
	....	⅛	62½	63	....	....	62½	62½	99.2	100.0	+ 0.8	
	....	1/16	31½	31½	....	....	31¼	33	99.2	94.7	− 4.5	
	....	1/32	Not	tested.	....	....	Regis	tered.	?	?	....	

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TABLE No. 25—(*Continued*).—TRIDENT METERS TESTED IN FEBRUARY, 1898.

Size. Inches.	No. of meter.	Size of stream. Inches.	ORIGINAL TEST. Meter. Pounds	ORIGINAL TEST. Scales. Pounds	Time in service. Months.	Total registration. Cubic feet.	SECOND TEST. Meter. Pounds.	SECOND TEST. Scales. Pounds.	REGISTRATION. Original test. Percentage.	REGISTRATION. Second test. Percentage.	REGISTRATION. Change in registration. Percentage.	Remarks.
$\frac{5}{8}$..	17 262	$\frac{3}{4}$	625	630	22	111 400	625	640	99.2	97.7	− 1.5	In good condition. When first tested was not as sensitive as should have been. Examination showed an eel-skin in disc chamber around disc, but no damage done. Skin was removed, meter reassembled and tested, with result given.
	....	$\frac{1}{4}$	$62\frac{1}{2}$	$62\frac{1}{2}$	....	....	$62\frac{1}{2}$	63	100.0	99.2	− 0.8	
	....	$\frac{1}{8}$	$62\frac{1}{2}$	63	....	....	$62\frac{1}{2}$	$63\frac{1}{2}$	99.2	98.4	− 0.8	
	....	$\frac{1}{16}$	$31\frac{1}{4}$	40	....	....	$31\frac{1}{4}$	36	78.1	86.8	+ 8.7	
	....	$\frac{1}{32}$	Not	tested.	....	....	Regis	tered.	....	....	....	
$\frac{5}{8}$..	17 280	$\frac{3}{4}$	625	624	22	115 000	625	652	100.2	95.9	− 4.3	
	....	$\frac{1}{4}$	$62\frac{1}{2}$	$61\frac{1}{2}$	....	....	$62\frac{1}{2}$	$65\frac{1}{2}$	101.6	95.4	+ 6.2	Meter in good condition. No wear apparent.
	....	$\frac{1}{8}$	$62\frac{1}{2}$	$62\frac{1}{2}$	....	....	$62\frac{1}{2}$	67	100.0	93.3	− 6.7	
	....	$\frac{1}{16}$	$31\frac{1}{4}$	$33\frac{1}{2}$	....	....	$31\frac{1}{4}$	39	93.3	80.1	−13.2	
	....	$\frac{1}{32}$	Not	tested.	....	....	Regis	tered.	....	....	....	
$\frac{5}{8}$..	17 366	$\frac{3}{4}$	625	623	23	101 000	625	624	100.3	100.2	− 0.1	
	....	$\frac{1}{4}$	$62\frac{1}{2}$	62	....	....	$62\frac{1}{2}$	$62\frac{1}{4}$	100.8	100.4	− 0.4	Meter in good condition. No wear apparent.
	....	$\frac{1}{8}$	$62\frac{1}{2}$	$63\frac{1}{2}$	....	....	$62\frac{1}{2}$	$62\frac{1}{2}$	98.4	100.0	+ 1.6	
	....	$\frac{1}{16}$	$31\frac{1}{4}$	$33\frac{1}{4}$	....	....	$31\frac{1}{4}$	32	94.0	97.7	+ 3.7	
	....	$\frac{1}{32}$	Not	tested.	....	....	250	250	?	100.0	....	
$\frac{3}{4}$..	17 384	$\frac{3}{4}$	$62\frac{1}{2}$	$62\frac{1}{2}$	24	124 000	625	636	100.0	98.3	− 1.7	Meter in good condition. No wear apparent.
	....	$\frac{1}{4}$	$62\frac{1}{2}$	$62\frac{1}{2}$	....	....	$62\frac{1}{2}$	63	100.0	99.2	− 0.8	
	....	$\frac{1}{8}$	$62\frac{1}{2}$	$62\frac{1}{2}$	....	....	$62\frac{1}{2}$	64	100.0	97.7	− 2.3	
	....	$\frac{1}{16}$	$62\frac{1}{2}$	$63\frac{3}{4}$	....	....	$62\frac{1}{2}$	$64\frac{1}{2}$	98.8	96.9	− 1.9	
	....	$\frac{1}{32}$	Not	tested.	....	....	$62\frac{1}{2}$	$65\frac{1}{2}$	?	95.8	....	
$\frac{3}{4}$..	17 394	$\frac{3}{4}$	$62\frac{1}{2}$	$62\frac{1}{2}$	22	132 000	625	642	100.0	97.4	− 2.6	Meter in good condition. No wear apparent.
	....	$\frac{1}{2}$	$62\frac{1}{2}$	$62\frac{3}{4}$	....	....	$62\frac{1}{2}$	64	100.4	97.7	− 2.7	
	....	$\frac{1}{8}$	$62\frac{1}{2}$	$61\frac{1}{2}$	....	....	$62\frac{1}{2}$	64	101.6	97.7	− 3.9	
	....	$\frac{1}{16}$	$31\frac{1}{4}$	$31\frac{1}{4}$	....	....	$6\frac{1}{4}$	$6\frac{3}{4}$	100.0	92.6	− 7.4	
	....	$\frac{1}{32}$	$6\frac{1}{4}$	7	....	....	Regis	tered.	89.3	?	....	

Mr. Kuichling. E. KUICHLING, M. Am. Soc. C. E.—This paper is a valuable addition to the literature of a subject which is of great importance in all large communities, and which has caused much worry to those who have charge of public water supplies. Many interesting experiments are set forth by the author, and the conclusions which he has deduced therefrom are presented so clearly and forcibly that little remains to be added in the discussion. Some of the topics, however, leave room for amplification, and in the following an attempt is made to bring to special notice the question of the permissible limit of error in registration at low rates of discharge; also to indicate the durability of meters by giving the results of a recent examination of a large number of small meters which have remained in use for long periods of time.

Taking conditions as they actually exist for the usual small meters in dwellings, boarding houses, etc., where water is not used for manufacturing purposes, it can be said that not more than 300 galls. per day are consumed by an average family of five persons, and that such use almost invariably occurs at the greatest practicable rate of delivery, or with the faucet wide open. With small service pipes and moderate pressures in the street mains, a maximum discharge of 200 galls. per hour through the meter may be assumed, so that for a consumption of 300 galls. per day in an ordinary dwelling, having all its pipes and fixtures in perfect order, the meter is in operation only about $1\frac{1}{2}$ hours, and is consequently idle about $22\frac{1}{2}$ hours each day. If, however, the pipes or fixtures in such a dwelling are defective, the leakage during the latter period of time will necessarily pass through the meter, and unless the same is very sensitive, much of this discharge may escape without registration.

The writer will now consider the magnitude of such leakage under ordinary conditions of pressure and public conscience. Usually the hot-water faucets are the first to commence dribbling, and next in order come the ball-cocks of water-closet tanks. By actual measurement of many such dribblings, which were regarded as insignificant by the householders, the writer has found a discharge of from 3 to 6 galls. per hour, or from 72 to 144 galls. per day, from a single faucet or ball-cock; and in many other cases where a dwelling was supplied from an attic tank of from 100 to 150 galls. capacity, and with the pipes and fixtures apparently in fair order, it was found that when the pressure was reduced soon after midnight to such extent as to prevent water from entering the tank through the open ball-cock, there would be little water available for use 6 or 8 hours afterward, notwithstanding that none of the fixtures had been used during the night. From these experiences, the writer has reached the conclusion that the leakage from defective pipes and fixtures in an average dwelling, during the aggregate period of $22\frac{1}{2}$ hours of each day when no

faucet is opened by any of the occupants, may easily become as large as the legitimate consumption before it attracts the notice of the householder. It therefore follows that if the advantage of a meter system is to be even approximately realized, the meters must be sensitive enough to record a reasonable percentage of a leakage which amounts to much in the course of 24 hours, but occurs at so small a rate of flow as to appear insignificant in comparison with the discharge of a wide open faucet. Mr. Kuichling.

The question now arises as to the requisite degree of sensitiveness or registration of the meter under these low discharges. In view of the fact that the magnitude of the leakage may easily reach 25% of the entire daily delivery of the water-works system, it would appear at first glance that the meter should exhibit, when passing water at the rate of about 72 galls. in 24 hours, or 3 galls. per hour, a registration of at least 50% of this quantity, so as to divide the loss equally between the consumer and the corporation furnishing the water; also, that the percentage of registration should rise rapidly as the rate of flow increases, so as to be practically correct when the water is drawn from one or more fully open faucets. By this plan, the water-works will be paid on the average for seven-eighths of the total delivery to each consumer, and its business can accordingly be conducted with a reasonable allowance for loss by under-registration, and without unduly increasing the price of the water. A long study of the problem from this standpoint has convinced the writer that the principle just mentioned is sound, and it only remains to be seen whether the indicated degree of sensitiveness can readily be secured by meter makers.

An examination of the various tests submitted and cited by the author, as well as of those previously made by the writer, demonstrates that nearly all the meters mentioned in the paper are capable of meeting the above-named requirement, and hence also that the principal mechanical difficulties in the case have been successfully overcome. This being the fact, there is accordingly no valid reason for manufacturers to complain of unreasonable demands for accuracy by the users of meters, and it only remains for them to devise means of making their products uniform in quality as well as low in price. It should also be stated in this connection that the aforesaid efficiency or "sensitiveness" of 50% registration for so low a discharge as 3 galls. per hour was determined about 9 years ago from numerous experiments with several "Crown" and "Thomson" meters of the small sizes for domestic use, and that the curves obtained by plotting the percentages of accuracy as ordinates to the corresponding discharges in gallons per hour as abscissas were closely alike. Furthermore, these tests showed that in both styles of meter the efficiency rose to considerably more than 90% for a flow of 8 galls. per hour; and as this rate required much less time for making a test than the

Mr. Kuichling. aforesaid lower rate, it was accordingly adopted as a standard for use in the water department, along with a corresponding minimum efficiency of 90 per cent. At discharges of over 50 galls. per hour, all the small meters should register correctly within 1 or 2 per cent.

With respect to durability and maintained accuracy of registration, the results of some recent examinations of small meters by the writer may be of interest. Before being set, all these meters were tested and found to register within the aforesaid limits, and they have remained in place undisturbed for the periods of time indicated. None of them gave evidence of being defective, and they were temporarily removed only for the purpose of ascertaining their condition. The tests for accuracy of registration were all made immediately after removal, and before taking the meters apart for inspecting their interior condition. If found worn or defective in any respect, the necessary repairs were made, whereupon the meters were re-tested and replaced. Unfortunately, no record of the details of the defects and repairs was kept, and hence the results of the examinations are only qualitative. It is also to be regretted that this inspection has hitherto embraced only a few styles of meter, the "Crown" greatly predominating. Furthermore, the water which passed through the meters was in all cases clear and free from any sediment or grit, except such as might come occasionally from a considerable disturbance of the distributing system, such as the repair of broken mains and the addition of new lines of pipe, whereby more or less roiliness of the water is generally produced for short times; also, except the particles of rust or other accretions which form in all cast or wrought-iron pipes and become detached when the flow occurs at an unusually high velocity. Table No. 26, moreover, relates to only a few representative cases of small meters taken at random out of a list of several hundred.

TABLE No. 26.

Style.	Number of examples.	Size.	Number of years in uninterrupted service.	Low-Flow Test.		High-Flow Test.	
				Rate of discharge, in gallons per hour.	Ratio of actual to registered discharge.	Rate of discharge, in gallons per hour.	Ratio of actual to registered discharge.
		Inches.					
Crown.....	4	¾	12 to 16	*41 to 300	1.10 to 1.29	900 to 1 020	1.06 to 1.18
"	3	½	10 " 16	*25 " 150	1.04 " 1.11	900 " 930	1.03 " 1.07
"	4	½	12 " 15	11 " 15	1.09 " 1.14	830 " 930	1.00 " 1.09
"	10	½	10 " 16	10 " 15	0.99 " 1.07	830 " 980	1.00 " 1.06
Hersey....	3	⅝	1 " 3	9 " 13	0.99 " 1.10	980 " 1 300	0.97 " 1.02
Union.....	3	¾	11 " 15	*15 " 50	1.00 " 1.16	1 080 " 1 200	0.98 " 1.00
Thomson...	2	⅝	2 " 4	15	0.98 " 1.19	930 " 1 060	0.97 " 1.00

NOTE.—* Denotes that no registration occurred for lower rates of discharge than those mentioned in the fifth column. In these cases there was always some slight defect of piston or gearing which caused undue friction.

An inspection of Table No. 26 shows clearly that the meters mentioned afford little room for adverse criticism, so far as durability and continued accuracy of registration are concerned provided that the water passing through them is practically free from grit, and that proper care is taken in their manufacture. This latter remark is prompted by the fact that in the aforesaid examination a meter was occasionally found which did not exhibit first-class workmanship or materials, and consequently gave a considerably larger ratio of actual to registered discharge, at both low and high flows, than appears in the table. The remedy for this condition necessarily lies with the makers, and can, doubtless, be attained by a more rigid system of shop inspection. Mr. Kuichling.

With respect to the design, accuracy and durability of the smaller sizes of meters, it thus appears that the mechanical problem has been practically solved, and that there now remains only the matter of improvement and commercial development. Between the different types or styles there seems to be little choice, except as to cost, original workmanship and facility or economy of making repairs; and in these respects the disc meters possess an undoubted advantage over those which are provided with rotating pistons. The writer, therefore, agrees thoroughly with the author in the belief that most of the water meters now in the market are reliable and durable, and that their use should become an essential feature of all systems of public water supply.

George W. Rafter, M. Am. Soc. C. E.—The author's proposition, that all water services should be metered, while strongly held to by many water-works managers, has always seemed to the writer to be so far unsettled that it is at any rate still debatable. It is from this point of view that the opposite ground will be briefly traversed in this discussion. Mr. Rafter.

To begin with, the writer agrees that there are always some services in regard to which there can be no question as to the propriety of applying meters. The difficulty appears to be to decide just when to stop. The author says meter everything. To this the writer objects, on the ground that such procedure entails, under the unbusiness-like methods which generally prevail in American cities and towns, a bill of expense, the end of which no one can foresee. The tendency in nearly all municipal business is to employ mediocrity at an ever-increasing scale of wages. The selection of the author, as Water-Works Trustee at Wyoming, is merely the exception that proves the rule, and cannot be taken to indicate any general tendency to substitute business methods in place of political favoritism in municipalities. On this point, however, the writer does not want to be too insistent, because he recognizes that there is now a struggle, in American municipalities, between the spirit of expediency, on the one hand, and the scientific spirit, on the other. In such a struggle the engineer ought to be an

Mr. Rafter. important factor, if for no other reason than that he is the one man in the community with some technical knowledge of municipal business. Indeed, if engineers and other technical people do their part, the struggle between expediency and science may in the end win out in favor of science; and when that day arrives the writer will be more disposed to accept the author's dictum on universal metering.

It seems clear to the writer that, before extensively adopting meters, the cost of maintenance should be carefully considered. Complete statistics, covering all the items of cost for a series of years, are, however, still quite rare, although in a few cities, as at Rochester, N. Y., enough has been learned to indicate the general trend. The meter department in Rochester was established under the direction of the former chief engineer, J. Nelson Tubbs, M. Am. Soc. C. E., who was satisfied that the cost per meter ought not to exceed about $1.50 per year, after the number in use became large enough to give good averages. The system of accounts, as designed by Mr. Tubbs, is very complete, and reference may therefore be made to the Rochester statistics as embodying, probably, as complete information as can be obtained anywhere. That the figures have not justified Mr. Tubb's original view may be ascribed largely to the deterrent effect of municipal politics.

By way of showing the Rochester meter statistics, Table No. 27 has been compiled from the Annual Report of the Executive Board of that city, wherein appear the essential figures of cost for the thirteen years from 1886 to 1897 inclusive.

Column (5) gives the amount received from meters sold to consumers. The Rochester Water-Works adopted the plan of metering some services at public expense; whereas others are metered only at the expense of the consumer, an attempt being made to distinguish between those requiring metering, as a matter of public policy, and those where meters presumably decrease the annual water rate to the consumer, somewhat. In Table No. 27, the cost of these latter is included as a part of the total expense of the meter department, for the reason that, as a matter of final expense to the whole community, it does not matter whether the meters are paid for by the municipality or by individual citizens who are water takers. It seems quite clear to the writer, therefore, that all items of expense attaching to meters so paid for should be included as an element of the final cost of the meter department in any city where the system in vogue at Rochester is pursued. It is fair, however, to separate this item in such statistics as are included in Table No. 27.

As regards the number of services in use at the end of each fiscal year, as per Column (8), it may be remarked that the statistics given in the annual reports since 1890 appear somewhat uncertain, although it is probable that the figures of Column (8) are so nearly right as to

Mr. Rafter.

TABLE No. 27.—Statistics of Meter Department at Rochester, N. Y.

Fiscal Year.		Number of meters in use at end of fiscal year.	Cost of new meters purchased during year.	Amount received from meters sold to consumers.	Total expenditure of Meter Department each year.	Total expenditure of Meter Department, less cost of new meters purchased.	Number of services in use at end of fiscal year.	Ratio of services to meters = Col. (3) ÷ Col. (8).	Approximate population.	Increase in number of meters during year.	Number of new services during year.	Number of meters permanently removed for various causes during year.	Daily use of Water per Capita. In Gallons.			Expenditure per meter.
Day of month ending.	Year.												From Hemlock Lake. Domestic system.	From Holly, Direct pressure, system.	Total of both systems.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
April 5........	1886	978	$1 552.45	$662.76	$5 452.85	$3 900.40	15 810	0.062	108 000	87	1 731	....	55.2	11.2	66.4	$3.99
" 4........	1887	1 094	2 582.97	1 144.47	6 468.29	3 885.32	17 454	0.063	113 000	116	1 644	....	58.5	11.9	70.4	3.55
" 2........	1888	1 558	9 648.65	867.38	15 073.23	5 424.58	19 407	0.080	119 000	464	1 953	....	57.9	12.2	70.1	3.48
" 1........	1889	1 700†	5 668.50	1 233.40	11 029.12	5 360.62	21 358	0.073	125 000	146*	1 951	....	54.3	12.5	66.8	3.15
" 7........	1890	2 115	8 912.88	1 322.00	15 517.85	6 604.97	23 000†	0.092	131 000	415	1 642†	....	51.5	12.9	64.4	3.12
" 6........	1891	2 844	14 540.88	5 518.62	24 525.31	9 984.43	24 868†	0.114	136 000	729	1 868	74	49.0	13.3	62.3	3.51
" 4........	1892	3 163	4 918.18	3 373.33	16 245.99	11 327.81	25 244†	0.125	140 000	319	376†	131	47.4	12.6	60.0	3.58
" 3........	1893	3 460	10 241.07	2 988.00	22 032.38	11 791.31	26 167†	0.132	144 000	297	923†	275	46.1	11.5	57.6	3.40
" 2........	1894‡	3 724	21 157.37	3 481.76	33 446.37	12 289.00	26 908†	0.138	148 000	264	741†	218	44.9	12.2	57.1	3.30
" 1........	1895	4 043	1 181.16	3 450.89	14 407.16	13 226.00	27 410†	0.147	152 000	319	502†	183	47.4†	11.7	59.1†	3.26
Dec. 31§	1895	5 157	5 245.55	9 6 6.32	16 387.62	11 142.07	28 512†	0.181	156 000	1 114	1 102†	143	50.0†	12.5	62.5†	2.88‖
" 31........	1896	6 005	8 729.30	7 564.81	26 021.33	17 292.03	29 500†	0.204	160 000	848	988†	226	60.0†	10.7	70.7†	2.88
" 31........	1897	6 497	6 311.30	5 839.14	22 317.42	16 006.12	30 000†	0.216	165 000	492	500†	170	65.3†	8.7	74.0†	2.46
Totals........	......	......	$100 690.26	$47 132.88	$228 924.92	$128 234.66	....	......	....	......	....	1 420	....	....	....	......
Means........	......	......	7 745.40	3 625.61	17 609.60	9 864.20	....	......	....	......	....	....	....	....	....	$3.28

* There is a discrepancy of 112 meters in the figures for this year. According to one set of figures in the annual reports, the total number set was 258.

† Approximate.

‡ New conduit from Hemlock Lake in service in October, 1894.

§ A short fiscal year here.

‖ The expenditure per meter for the short fiscal year ending December 31st, 1895 (9 months) was $2.16; $2.88 per meter is on the same basis for twelve months.

Mr. Rafter. permit their use without material error. In the same way, the population figures, as per Column (10), are approximate, except for the census year 1890, in which the total population is given at 133 896. The figures of Column (10) are intended as approximate means for each fiscal year.

The previous remarks in regard to the uncertainty as to the number of services in Column (8) also apply to the number of new services as per Column (12).

The statistics of the number of meters permanently removed for various causes are first given for the fiscal year ending April 6th, 1891. The interesting fact that, in the years from 1891 to 1897, inclusive, a total of 1 420 meters was permanently removed for various causes, is brought out by Column (13), in which these figures appear.

Table No. 27 is so clearly self-explanatory as to render further discussion unnecessary. It seems to the writer to justify clearly the position taken at the beginning of his discussion, that the propriety of universal metering, under existing conditions, in American municipalities is, at any rate, a debatable question. It may be pointed out, however, that the figures of Column (17) do not take into account any allowance for interest on money invested, sinking fund, or for meters permanently removed and going to the scrap heap; nor do they include additional service in the business office on account of the greater complication of meter accounts. Making an addition for these several items, the average cost per meter, for the period covered by Table No. 27, becomes about $4.40, instead of $3.28, as given at the foot of Column (17).

Mr. Le Conte. L. J. Le Conte, M. Am. Soc. C. E.—The writer is a firm believer in water meters being the best and only equitable controllers of water waste. It is true that some meters will not register small leaks in plumbing, but this fact is not a matter of vital import in the great problem, taken as a whole. The main feature which must not be lost sight of is that the percentage of waste which it is desired to suppress, by the introduction of meters, is not 15 to 20% of the total water supply, but is far more likely to be 65 to 70 per cent. Hence, in a broad sense, it is useless to discuss small percentages. Many writers are continually harping upon the supposed fact that small leaks, due to defective plumbing alone, constitute the main source of water waste. This may be true in isolated cases on a small scale, but, generally speaking, it is far from true, because instances are now too numerous where meters have been suddenly introduced, and, as a result, that infallible test, the coal-bill at the pumping-works has been likewise suddenly reduced as much as 40 per cent. Such close relation between causes and effects leaves little or no room for doubt or discussion.

The main trouble is willful waste. A careful study of the extravagant consumption of water in any modern city, supplying water to

consumers without the use of meters, will generally lead to a subdivision of the subject into three categories: Mr. Le Conte.

First.—Legitimate consumption equals 40% of the total water supply.

Second.—Willful waste equals 40% of the total supply.

Third.—Defective plumbing and leaky valves and joints in the distribution system equal, say, 20% of the total supply.

Now, the first two can and will be controlled most effectually by meters, while the third will certainly be very materially reduced by the fact that the general adoption of the meter system will itself invariably enforce the introduction of a much higher class of plumbing work throughout the city. This, of course, means a less number of small leaks such as the meters are unable to register.

The accuracy of the meters tested by the author is certainly quite remarkable, and the writer thinks they are really more accurate than the exigencies of the case require. If the meters have an error of 7 to 8%, that certainly cuts no figure in the water-waste problem, and since this error is in all cases, practically, in favor of the consumers, they have no just ground for complaint.

As to the durability of meters, one can only speak in a broad, general way, since local circumstances have great weight in all cases. The average life of a meter, which it is reasonable to expect, depends chiefly upon the character of the water. In localities where the supply is taken and delivered directly from rivers, the waters of which are heavily charged with siliceous sediment, the wear and tear on the meters is, of course, enormous, and the apparatus is practically used up in from 2 to 5 years; the repairs being correspondingly heavy. In all such places it does not pay to furnish meters except to control the supply to the largest consumers. The smaller ones can best be held in check by inspection from time to time. Where the water supply is naturally clean, or is made so by sedimentation; or, better still, by filtration, then the water passing through the meters is practically free from silty materials, and, under favorable circumstances, the life of the meter may and does become very much prolonged, possibly 15 to 16 years or more. In such cases the item of annual repairs will be comparatively light, not to exceed, say, 2 to 3% of the first cost. It may be fairly stated that the grand average useful life of a meter is approximately 10 to 12 years of very fair service, assuming that it is given ordinary attention and care.

A good new meter will register within 1.5 or 2% easily, and the annual increment of this error will generally be something less than 1% —sometimes much less.

The writer agrees with the author in the statement that the only fair and honest way to sell water is by meter measurement.

Mr. Hill. JOHN W. HILL, M. Am. Soc. C. E.—Considering the several criticisms on the paper; some of these undoubtedly are just, and, within the time at the author's disposal, the errors and omissions will be corrected.

When the tests were started they had only one object in view, viz., a comparison, upon a uniform footing, of the less expensive with the more expensive water meters, under all the conditions of daily service liable to occur in the use of meters on domestic service pipes, and, to avoid the chance of error in the work, every precaution was taken, within the limits of the crude apparatus with which the author was compelled to work.

Referring to the temperature of water which was taken for each test: The discharge of the meters being noted in pounds, this weight was divided by the weight of water per cubic foot at observed temperature, to reduce the discharge to the same kind of unit measurement as the registry of the meters, *i. e.*, cubic feet, and it was just as convenient to divide the weight of the contents of the cask by the weight due to the actual temperature of the water as by any other weight. The author does not regard this as a refinement, but as an essential part of the data in a series of tests of this nature.

The scale was in excellent order, and during the experiments was often tested for "sensitiveness" by the addition and subtraction of small weights, and for accuracy, by test weights of known value. The cask was bottle tight, and to prove the absence of leakage was filled, weighed and allowed to remain over night, without change of weight. The apparatus was so arranged that no water could reach the cask unless it came through the meter under test.

The author cannot quite agree with Mr. Smith that the errors of measurement found with the smaller orifices should be excluded in stating the average error of water meters. If the meter would never be required, or infrequently required, to measure the small streams of 10 to 42 galls. per hour, then the average based upon these and larger streams together, would be manifestly fair; but it is a fact generally recognized that the leaks in domestic water appliances are conditions that must be met if the water meter does its whole duty; and it is the supposed incapacity of water meters to properly account for the small streams represented by leaks which has been one of the objections urged by water-works managers to the general adoption of the meter system on domestic service pipes.

The author is heartily in accord with Mr. Kuichling's view, that a reliable water meter should give a reasonable account of the leaks of pipes and fittings in domestic plumbing, and it is gratifying to know that the modern meter is abundantly capable of doing this, with a degree of accuracy which, in some instances (shown by Table No. 1), is really marvelous.

The four Trident meters tested were not provided with extension dials, and only one of these (No. 23 176) had been in service prior to these tests, but this meter was taken off the service pipe and tested without opening and cleaning it, and, except for the small stream of 11 galls. per hour, gave quite as good results as the unused meters. The simplicity of construction, strength, and general adaptation to practical uses of this meter appealed so strongly to the author as to justify him in recommending it as one of the few meters to be adopted for use by the Trustees of the Wyoming Water-Works. Mr. Hill.

With reference to the test of strength of the working parts of meters by suddenly applying water pressures of 100 lbs., more or less, it must not be overlooked that this was an unbalanced pressure, the pressure on the outlet side of the meter at such times being the atmosphere. With a meter connected in the line of service pipe such a test as Mr. Thomson very properly suggests could have no significance, because the pressure upon both sides of the meter would be approximately alike, but the sudden application of this pressure to a meter with no resistance above the atmosphere upon the outlet side, subjects it to a shock which will seldom occur in practice, and if the meter is not well built, such treatment, often repeated, is very liable to injure it.

Mr. Thomson has misunderstood the author with regard to the character of the water passed through these tested meters. The Wyoming water is of high purity, and carries no sand or grit, and excepting the salts of iron, it contains no material calculated to have any deleterious influence on the long-continued operation of a water meter. The 3-in. hot-water Worthington meters, however, were tested with Ohio River water, which, among other inferior qualities that it possesses, carries a large amount of gritty suspended matter. Mr. Thomson also regards the obstruction of meter or loss of head generally as of no great importance, while Mr. Smith thinks the importance of the loss of head cannot be overestimated. This wide disagreement of two eminent experts on water meters is very painful to the author, and he would suggest that if these gentlemen will get together and reach a compromise view, he will gladly accept their joint decision. Meanwhile, the author is of the opinion that, without injury to the meter itself, efforts should be made to secure a construction which will absorb the least portion of the static head in overcoming meter resistances.

It was thought by the author that the figures in the column headed "Ratio of Tank to Meter" in Table No. 1, would readily convey to the reader's mind a correct conception of the relation of the meter registry to the actual quantity of water discharged, without the aid of diagrams. To remedy this omission, the curves on the diagrams, Figs. 17 and 18, have been plotted with the reciprocals of the quanti-

Mr. Hill. ties in the seventh column of the table, and the discharges of the meters in gallons per minute, as co-ordinates, Fig. 17 containing the data obtained from the tests for sensitiveness of the piston and inferential meters, and Fig. 18 the same data obtained from the disc meters.

The author's reason for comparing the actual discharge of a meter for any given standard orifice, with the discharge obtained from the curve, is as follows:

During the tests for accuracy of measurement and sensitiveness to varying rates of discharge, the pressures were taken only on the inlet side of the meters. From these tests the data of Table No. 1 were obtained. Afterward the plain pipe was substituted for the meters and the data of Table No. 6 obtained; and finally the apparatus was further altered to take pressures on both sides of the meter, and the data of Table No. 5 were noted, but at this time, owing to press of other duties, the notes were limited to the pressures on the inlet and outlet pipes, and no note was taken of the reading of the meter or the actual discharge of water.

The author, however, had no reason to believe that any change occurred in any meter which would cause its discharge for a given pressure on the inlet side and given standard orifice, to vary from the discharge for the same pressure and orifice when the notes for Table No. 1 were being taken, and, for example, assumed that with 29 lbs. pressure on the inlet side of the Worthington meter, the discharge was the same as when this pressure occurred during the tests for accuracy and sensitiveness.

The curves were based upon the actual discharge at the pressures noted in Table No. 6, and are theoretical only so far as the well-known laws of hydraulics are held to apply to the discharges of the plain pipe by pressures at the inlet side, above and below the pressures noted in the table.

Upon reflection, however, the author thinks Mr. Thomson may be correct in assuming that the discharge of the meters should be compared with the discharge of the plain pipe, and not with an assumed discharge of the pipe under the pressure which was had on the inlet side of the meters during the tests, for such pressure could not obtain with the plain pipe, because more of the static head is expended in producing velocity, and less in overcoming frictional and other resistances. Therefore, the assumed head on the plain pipe is an impossible head under the conditions of the author's tests, and could be had only by a large increase of the static pressure on the service pipe, which in a reservoir water-works is not conveniently to be had. With this explanation, the author submits Table No. 28, showing the relation of the actual discharge of the meters to the possible discharge of the unmetered service pipe. This table ignores the differences of pressure

Mr. Hill.

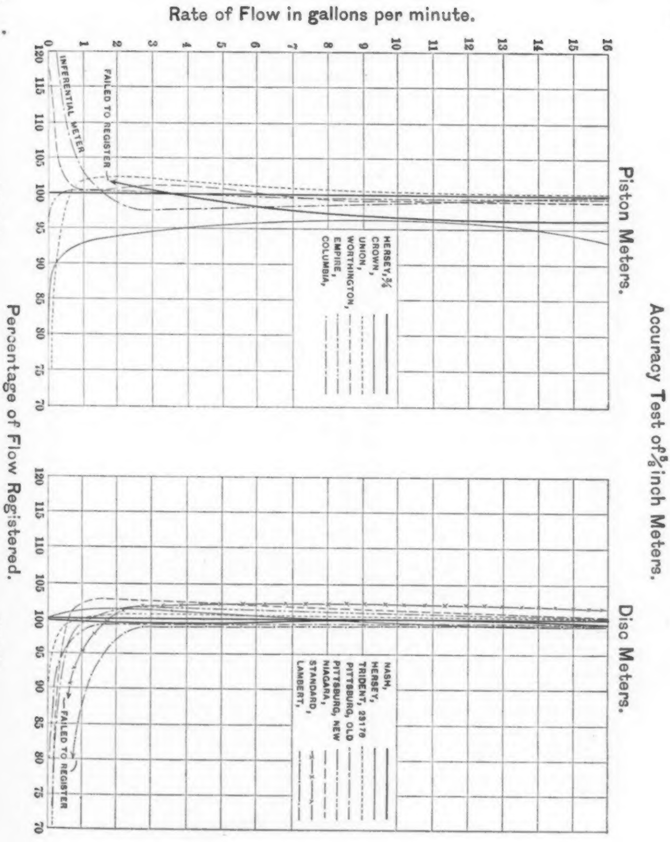

FIG. 17.

FIG. 18.

Mr. Hill. on the inlet side of the meter and on the inlet side of the plain pipe. The data for Table No. 28 are derived from Tables Nos. 6 and 7.

TABLE No. 28.—REDUCED DISCHARGE OF SERVICE PIPE BY INTRODUCTION OF METERS.

Meter.	Gallons per hour, by meter.	Gallons per hour, plain pipe.	Percentage of reduced capacity.
	PISTON METERS.		
Worthington	828.27	......	86.14
Crown	872.85	......	90.78
Hersey	913.52	961.49	95.01
Empire	746.60	......	77.65
Union	940.94	......	97.86
Worthington	531.30	......	92.02
Crown	546.31	......	94.62
Hersey	559.95	577.37	96.98
Empire	503.90	......	87.28
Union	581.90	......	100.78
Worthington	172.25	......	98.76
Crown	172.68	......	99.00
Hersey	172.58	174.42	98.05
Empire	167.44	......	96.00
Union	178.06	......	102.09
	DISC METERS.		
Nash	933.14	......	97.05
Hersey	868.87	......	90.37
Trident, No. 23 178	926.78	......	96.39
Trident, No. 23 179	900.72	......	93.68
Trident, No. 23 180	873.18	......	90.82
Trident, No. 23 176	915.81	961.49	95.25
Pittsburg, No. 8 011	896.92	......	93.28
Pittsburg, No. 10 798	907.36	......	94.37
Niagara	894.93	......	93.08
Standard	938.18	......	97.58
Lambert	911.27	......	94.78
Nash	573.79	......	99.38
Hersey	556.68	......	96.42
Trident, No. 23 176	556.23	......	96.34
Pittsburg, No. 8 011	548.74	577.37	95.04
Pittsburg, No. 10 798	557.06	......	96.48
Niagara	548.71	......	95.04
Standard	571·70	......	99.02
Lambert	560.57	......	97.09
Nash	172.70	......	99.01
Hersey	172.11	......	98.68
Trident, No. 23 178	173.52	......	99.48
Trident, No. 23 179	169.19	......	97.00
Trident, No. 23 180	167.95	......	96.29
Trident, No. 23 176	174.50	174.42	100.05
Pittsburg, No. 8 011	175.71	......	100.74
Pittsburg, No. 10 798	170.71	......	97.87
Niagara	168.95	......	96.86
Standard	175.23	......	100.46
Lambert	173.03	......	99.20
	INFERENTIAL METER.		
Columbia	762.43	961.49	79.30
Columbia	511.99	577.37	88.68
Columbia	172.93	174.42	99.15

The anomaly is presented in this table of some of the meters passing more water than the unmetered pipe, but this, it will be observed, upon referring to Tables Nos. 6 and 7, is due to a greater static head

Mr. Hill.

Loss of Head of 5/8 inch Meters

Rate of Flow in gallons per minute.

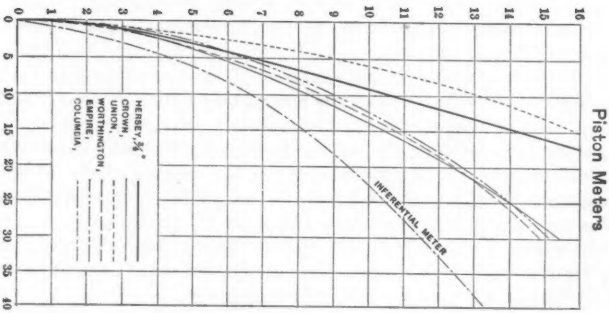

Fig. 19.

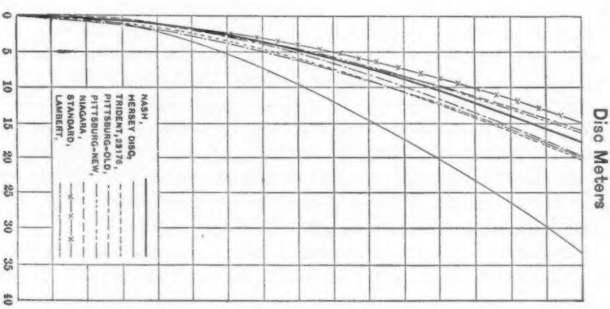

Fig. 20.

Loss of Head in pounds per square inch.

Mr. Hill. on the service pipe at times of testing certain meters than at the time of testing the discharge of the plain pipe.

The percentage losses of head in Table No. 5 and the percentage reduction of capacity of the service pipe by meter (Table No. 7) were intended only to show what these data were under the conditions of the tests described by the author. To remedy one objection to Table No. 5, the author has computed the discharge of the meter in gallons per minute, which, with the losses of head in pounds per square inch, given in column 5, furnishes the co-ordinates of the curves on the diagrams (Figs. 19 and 20).

It is true that the introduction of the meter system for water measurement represents to any community a comparatively large outlay, and the maintenance of the system a continual expense, but the author believes that the equity in charges for water service by the meter system will be justified, both to the consumer and the municipal corporation, and in the end both will be gainers. The practice of allowing "John Smith" to draw and waste all the water he can from a given service pipe, by paying so many dollars per year, answered the purpose in the days of high water charges and expensive water meters, but with a constant shrinking of charges for water, and low-priced, accurate, durable water meters, this primitive practice should no longer prevail, and measurement of the water actually drawn should be substituted for a wild guess as to the probable consumption by an average household.

The statistics, from the records of the Rochester Water Department, of water consumption and meter measurement, presented by Mr. Rafter, are very interesting and instructive, and might be amended by another column in the Table (No. 27) showing the saving to the water department in those instances where meters are used, by the substitution of meters for survey rates. Aside from the fact that the universal metering of service pipes gives the water-works manager a complete command of the commodity which he is distributing, and proportions the burden of cost among the customers more equitably than by the survey system, it admits of such an adjustment of the water rates as will produce the revenue necessary for the proper support of this branch of the municipal government, without favoring one class of consumers at the expense of another.

Referring to the consumption of water per average household. This is a matter which admits of wide discussion. Data have come into the author's possession which show the daily per capita consumption to range from 7.5 to 22 galls., including all the usual purposes to which water is applied about a modern residence. These figures correspond to 2 200 and 6 440 cu. ft. per year for a household of six persons. Mr. Smith estimates 10 000 cu. ft. as the average annual work of a $\frac{5}{8}$-in. water meter, while Mr. Harlow finds from five years' records for Wil-

kinsburg, Pa., an average consumption of 7 500 cu. ft. per annum per household. Mr. Kuichling's estimate of 60 galls. per capita per diem represents an average consumption of 17 570 cu. ft. per annum for a household of six persons, but this, doubtless, is intended to include the public consumption of water for street sprinkling, sewer flushing, extinguishment of fires, and perhaps other uses in addition to the purely domestic consumption by a family. Dexter Brackett, M. Am. Soc. C. E.,* from investigations in Boston and other cities, furnishes data for the following annual minimum and maximum consumption for a family of six persons: Mr. Hill.

	Cubic feet per annum.
Boston, Mass	4 860 — 17 274
Worcester, Maas	3 572 — 6 850
Fall River, Mass	2 460 — 7 466
Newton, Mass	2 020 — 7 759
Yonkers, N. Y. (average)	6 266

The author's experience indicates that the consumption for purely domestic purposes by a family of six persons will vary from 4 500 to 10 700 cu. ft. per year. The larger consumption, in all instances, is for houses fitted with modern plumbing, and the use of water for private stables, and the smaller consumption for houses with less pretentious water appliances and the consumption of water limited to house use.

In closing this discussion the author wishes to thank the members of the Society who have so earnestly and ably participated in the discussion of a subject of constantly growing interest and importance to municipal corporations and water consumers. He felt that there must be locked up somewhere a large amount of valuable information upon the "accuracy and durability in service of water meters" and that a random shot, well sped, might discover some of it. That this opinion was well founded is demonstrated by the valuable matter brought out in the discussion of this brief paper. Doubtless other papers and discussions of this topic in the future will go far toward overcoming the hesitation of many water-works officials in the general adoption of the meter system of water measurement.

* *Transactions*, Am. Soc. C. E., Vol. xxxiv, p. 189.